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Modeling complex legal cases as a Bayesian network using idioms and sensitivity analysis with the Collins case as a complete example

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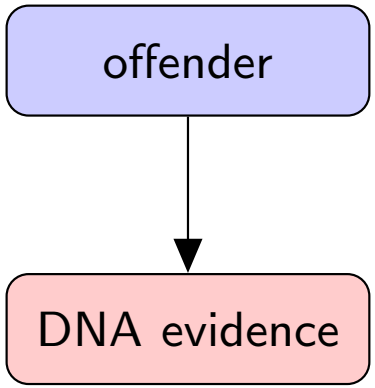
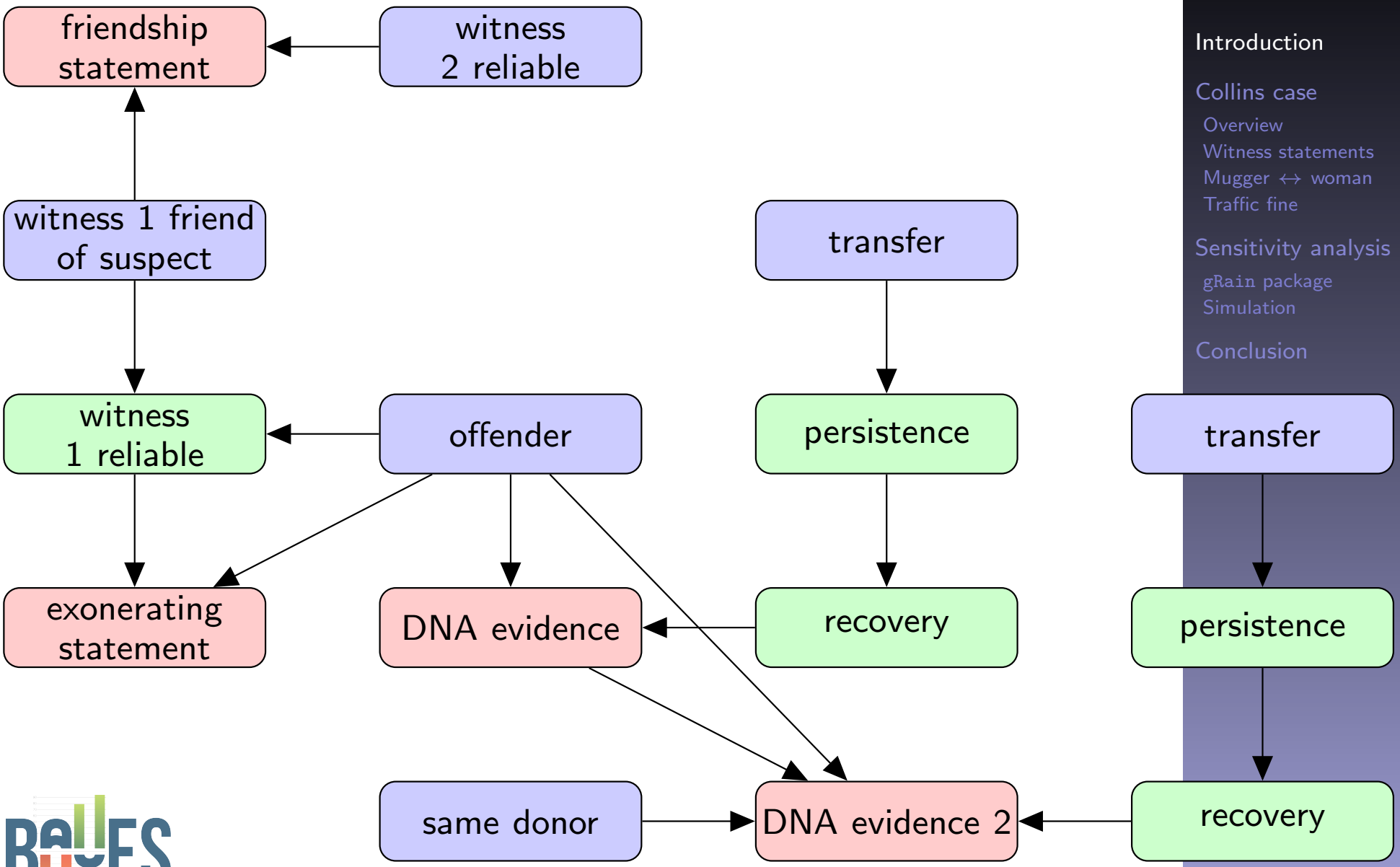
September 6, 2017

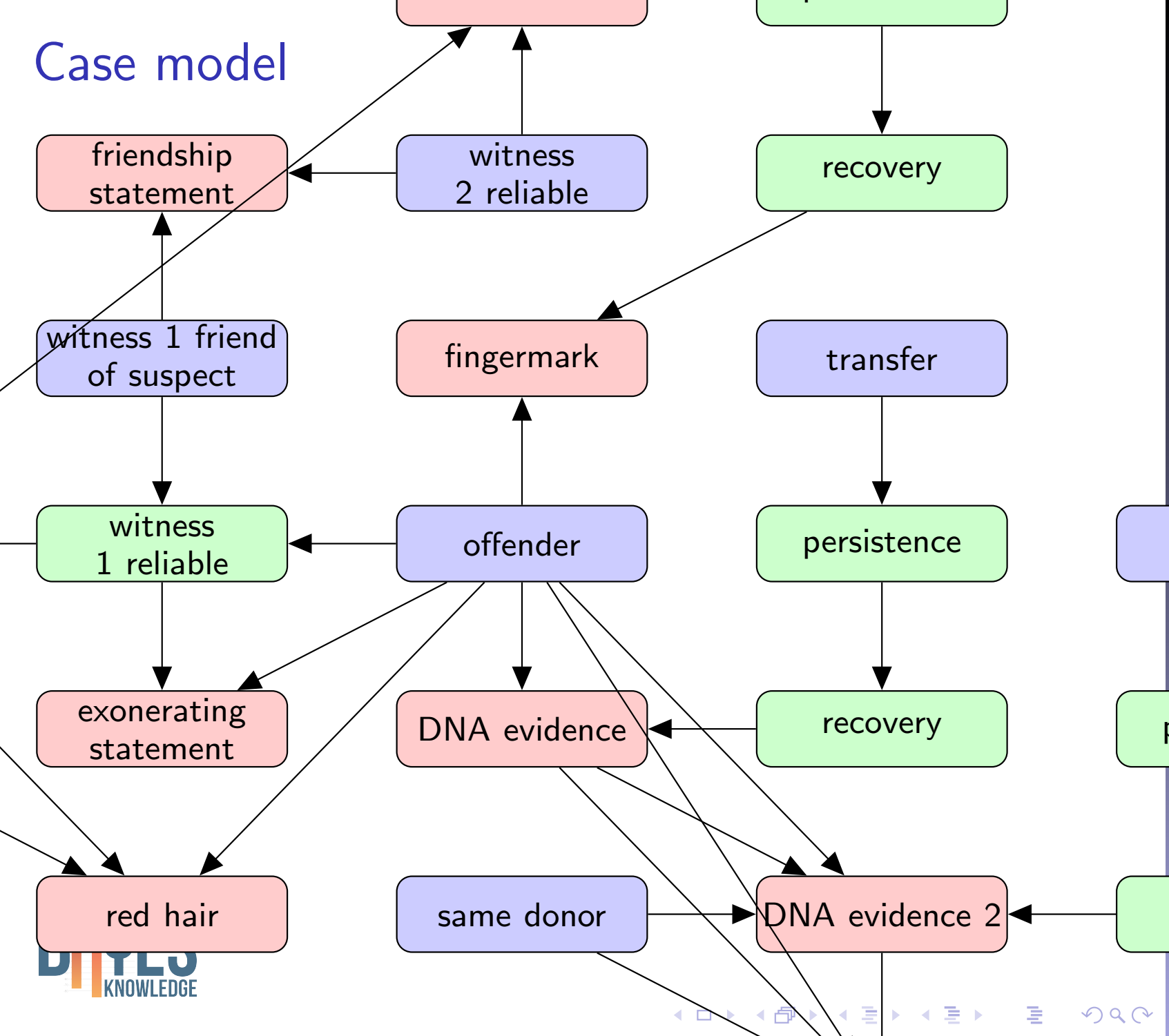
Evidence model



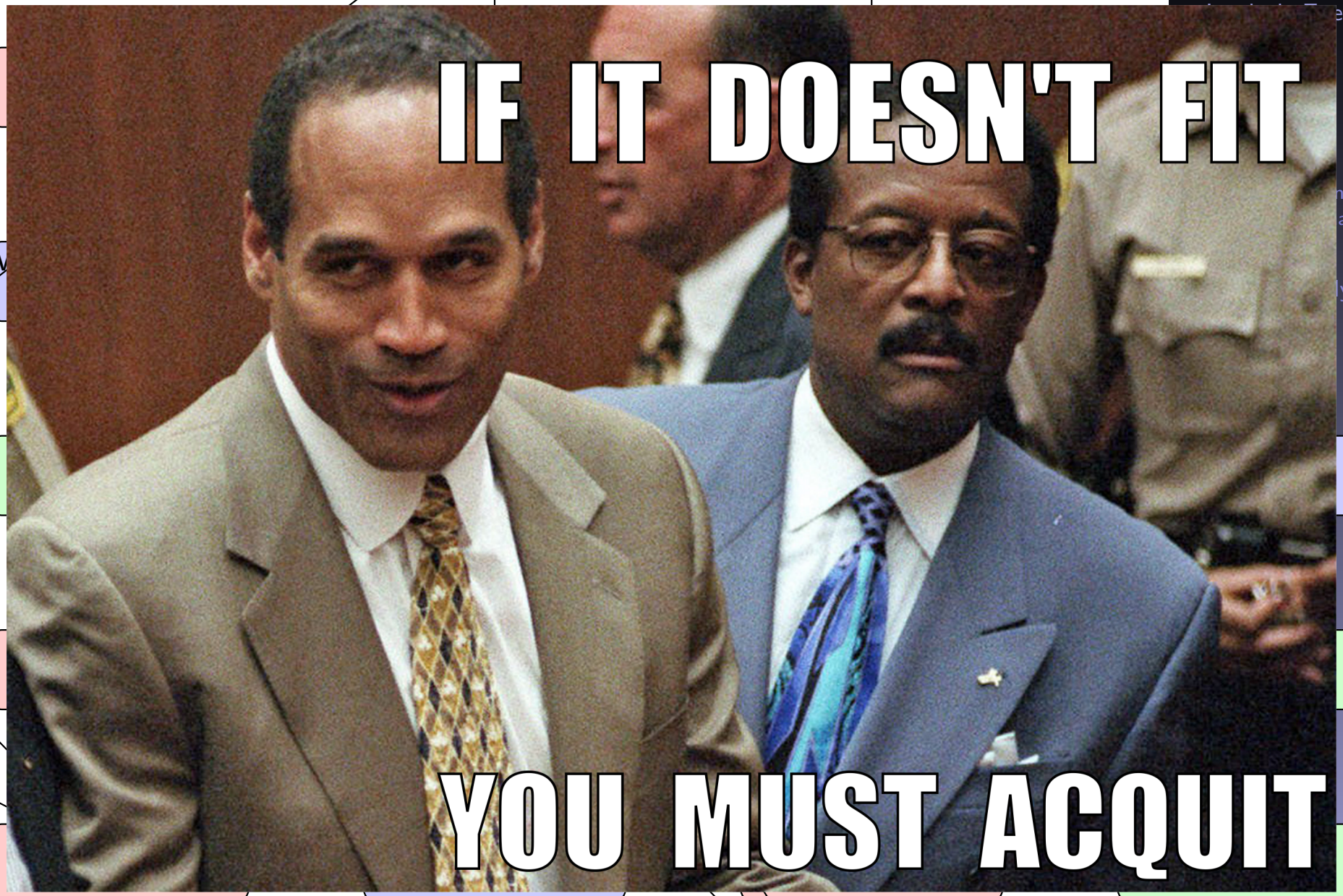
Case model


friendship statement
witness 2 reliable
witness 1 friend of suspect
transfer
witness 1 reliable
offender
persistence
transfer
exonerating statement
DNA evidence
recovery
persistence
same donor
DNA evidence 2
recovery

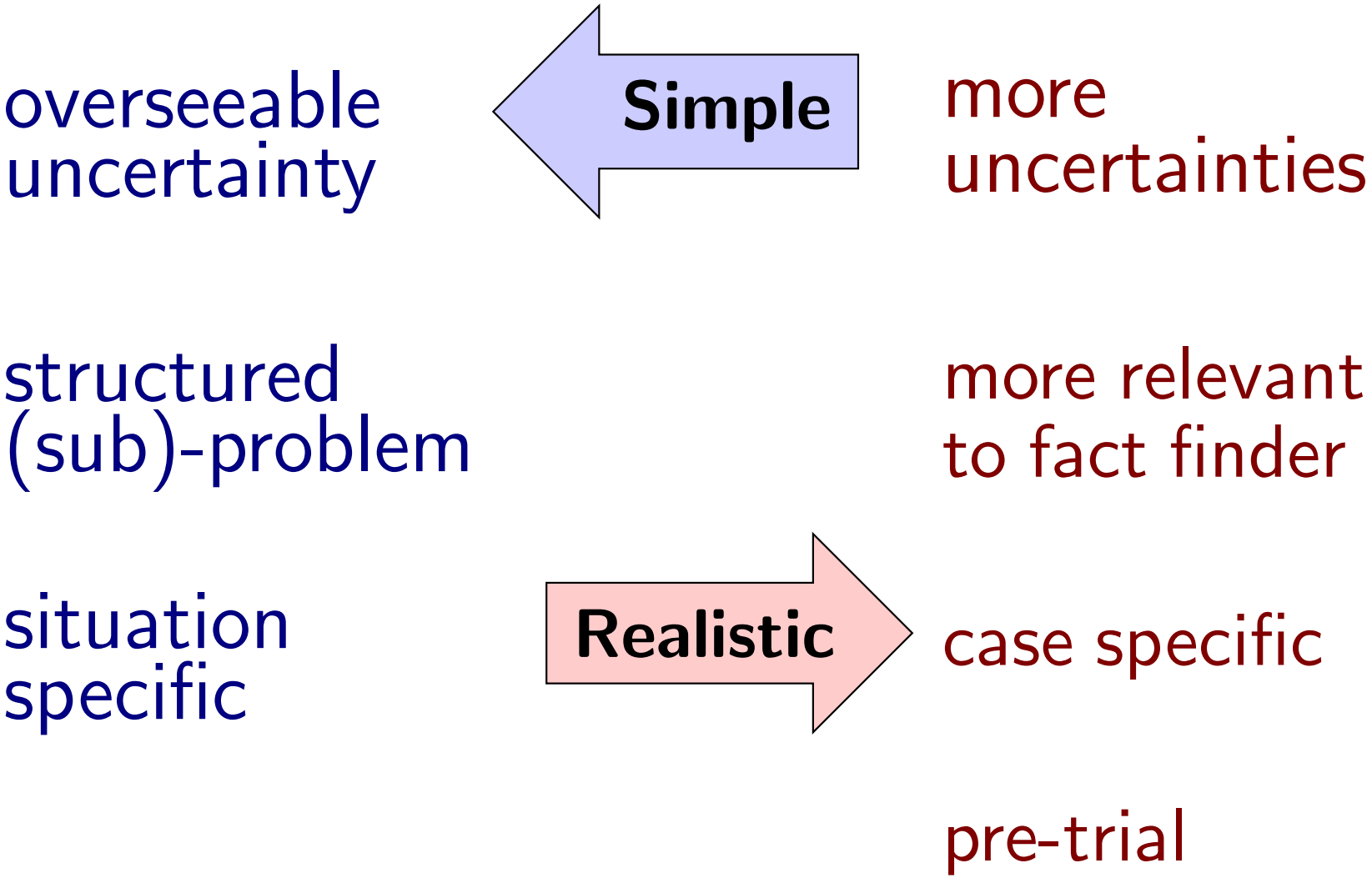
Case model


friendship statement
witness 2 reliable
recovery
witness 1 friend of suspect
fingermark
transfer
witness 1 reliable
offender
persistence
transfer
exonerating statement
DNA evidence
recovery
persistence
red hair
same donor
DNA evidence 2
recovery

Case model



Evidence model $\leftrightarrow$ Case model



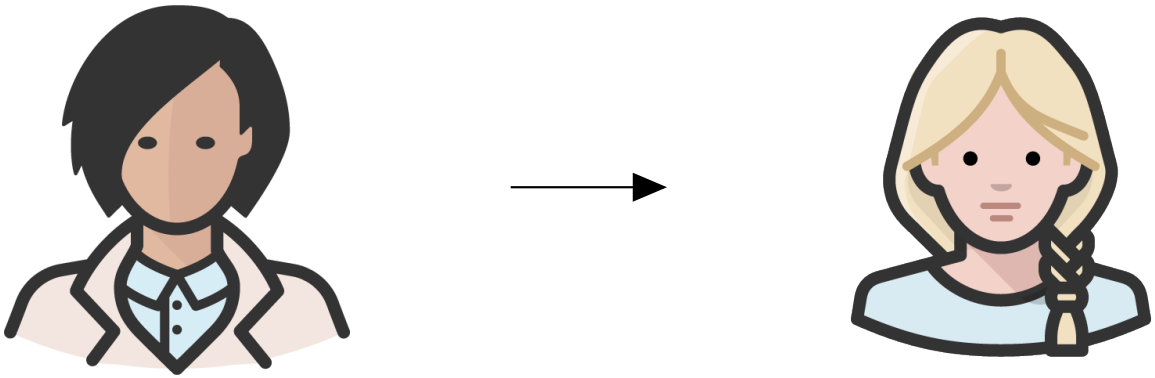
Collins case

On June 18, 1964, a woman named Juanita Brooks was walking home from grocery shopping. As she made her way down an alley, she suddenly felt herself being pushed to the ground. When she looked up, she saw a young woman with a blond ponytail running away down the alley with her purse.

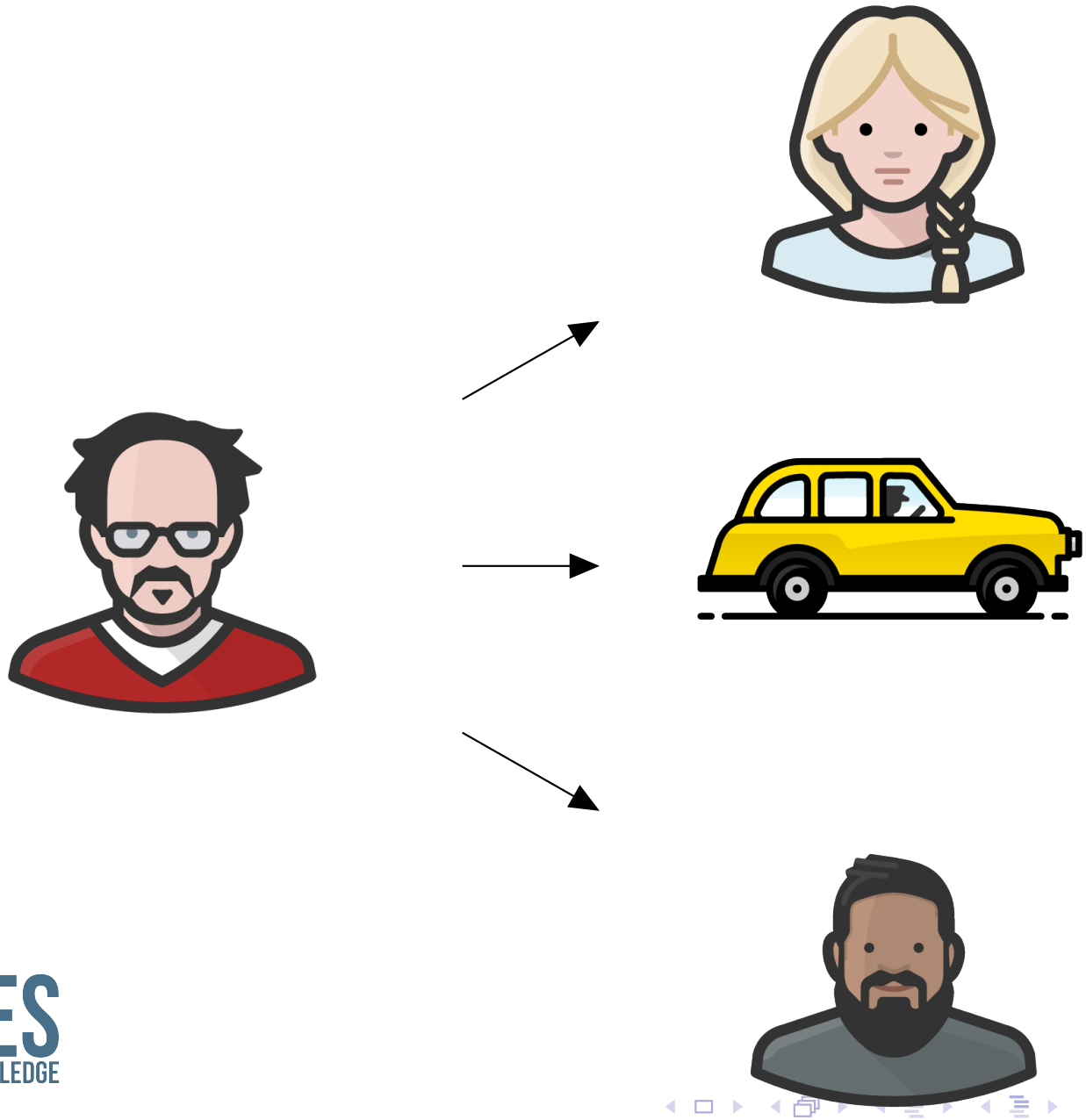
Near the end of the alley, a man named John Bass saw a woman run out of the alley and jump into a yellow car. The car took off and passed close by him. Bass subsequently described the driver as black, with a beard and a mustache. He described the woman as Caucasian, slightly over five feet tall, with dark blond hair in a ponytail.

Several days later, the police arrested Janet Collins and her husband Malcolm Collins.

Juanita Brooks witness statement



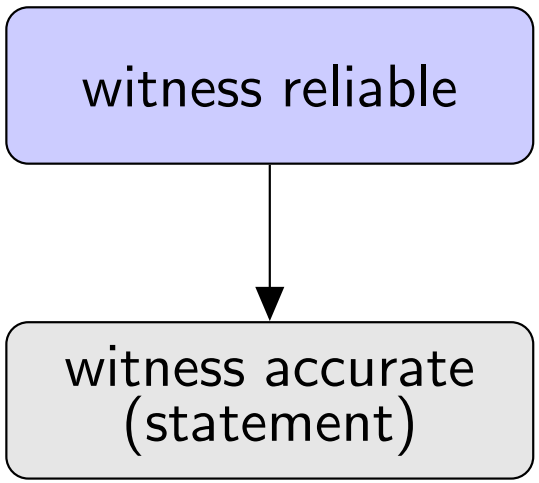
John Bass witness statement



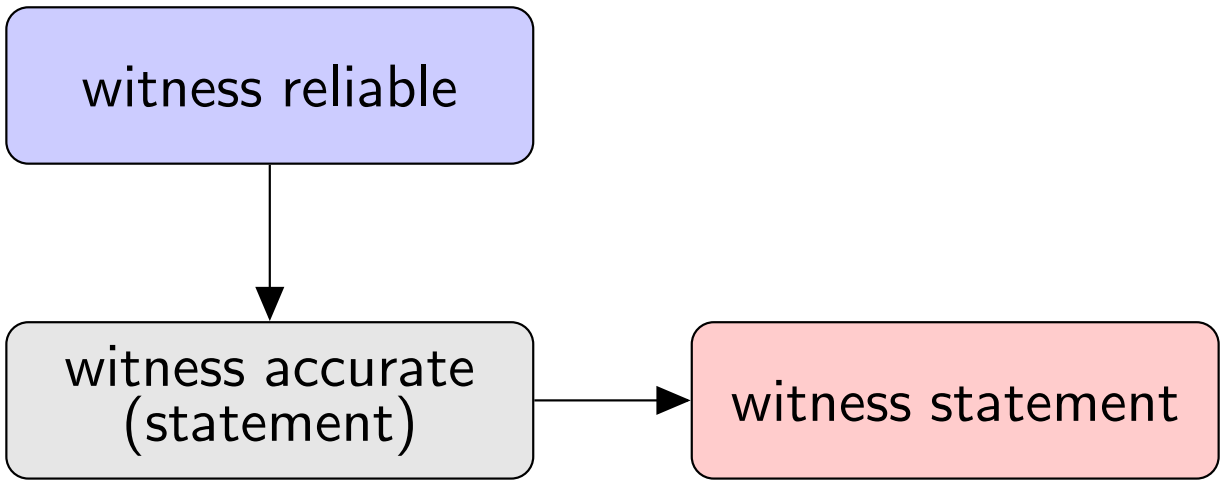
Witness statement - idiom

witness reliable

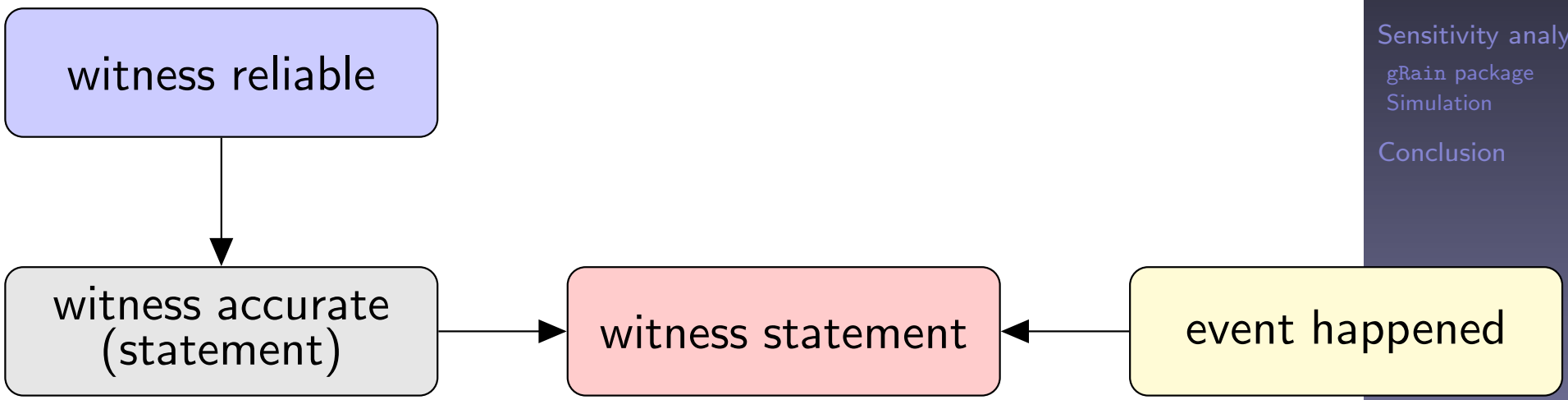
Witness statement - idiom



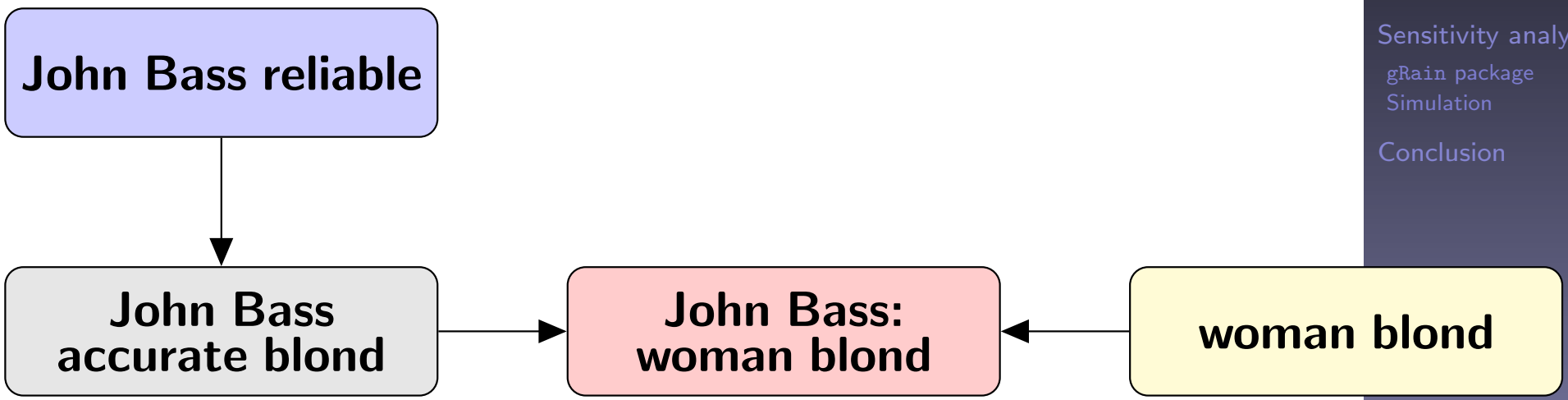
Witness statement - idiom



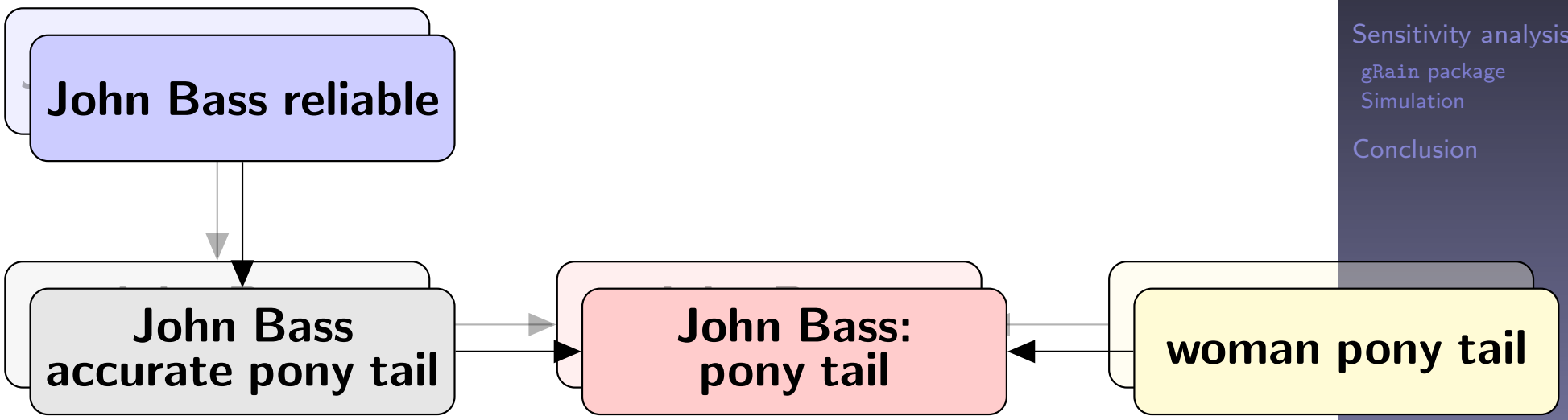
Witness statement - idiom



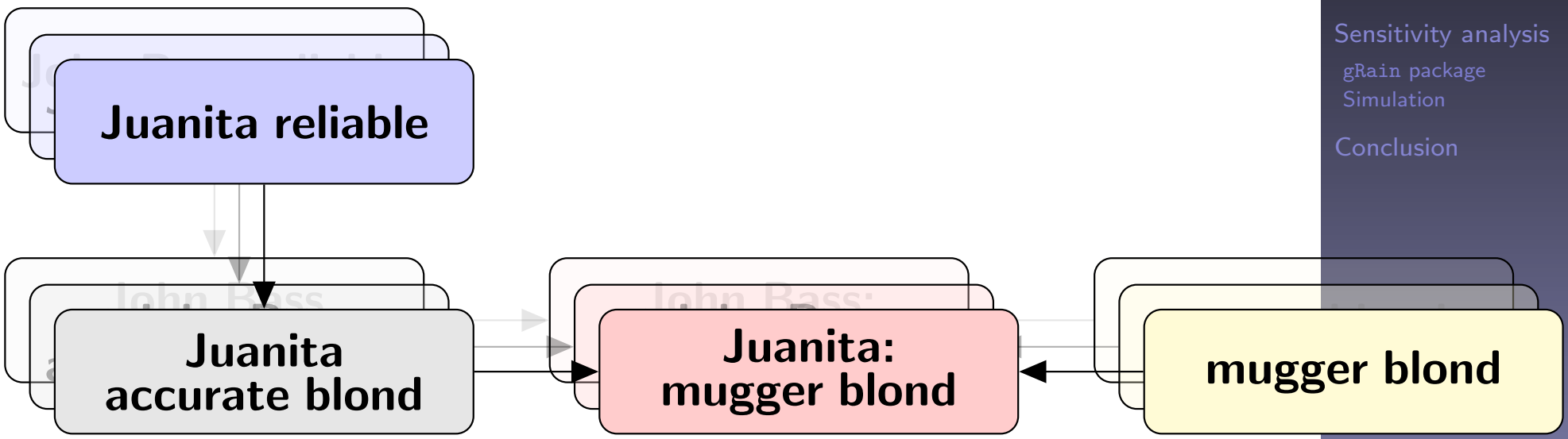
Witness statement - idiom



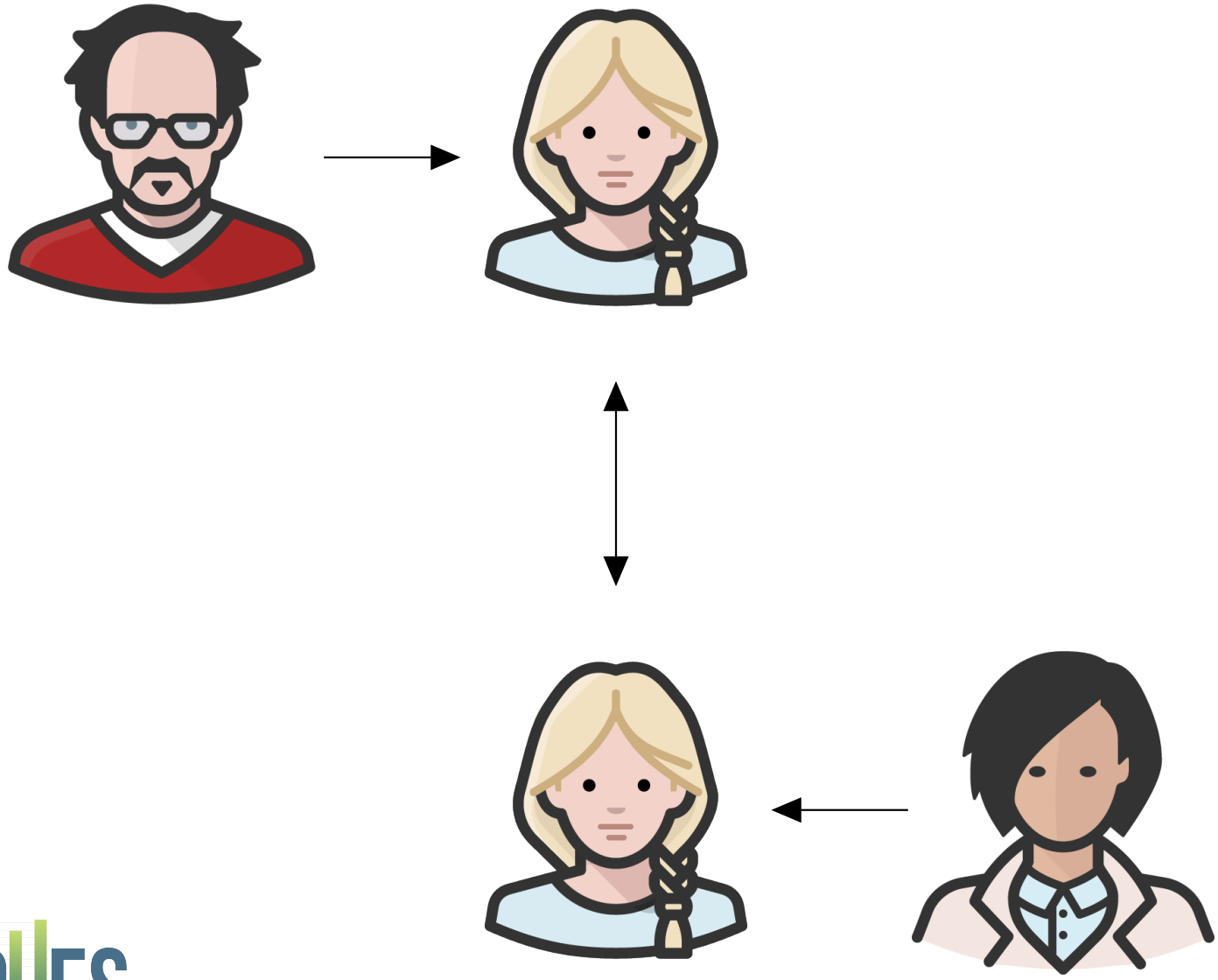
Witness statement - idiom



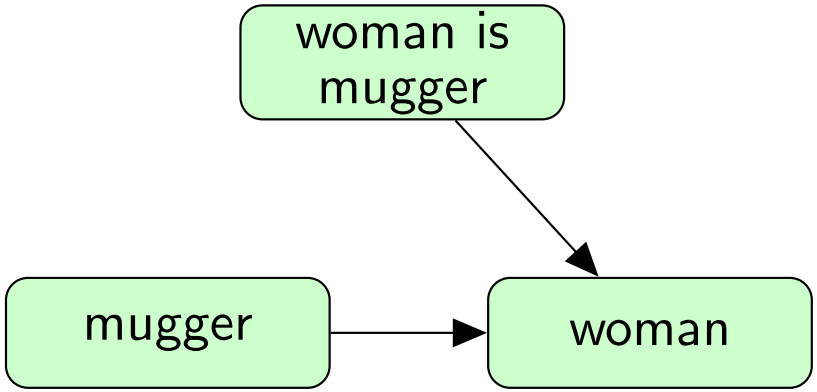
Witness statement - idiom



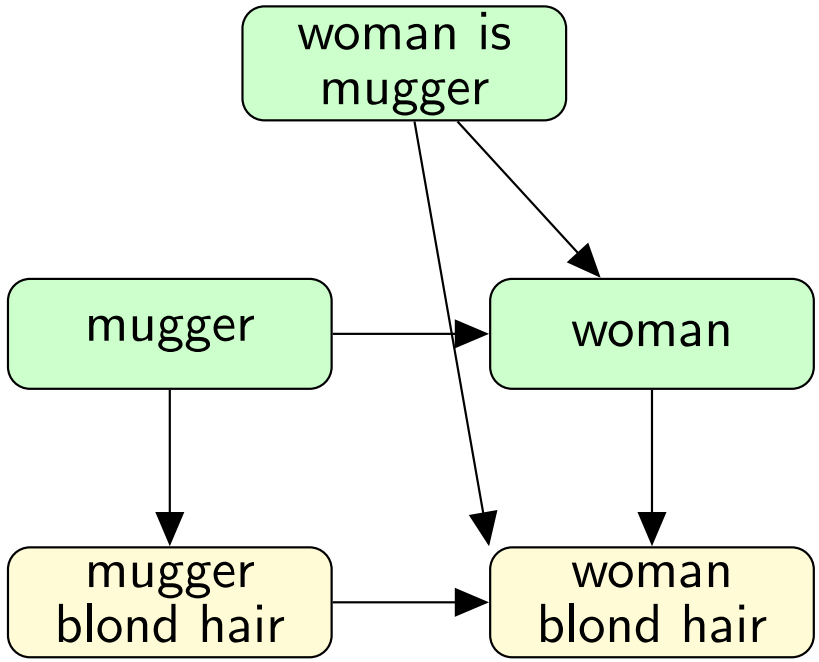
Blond woman evidence



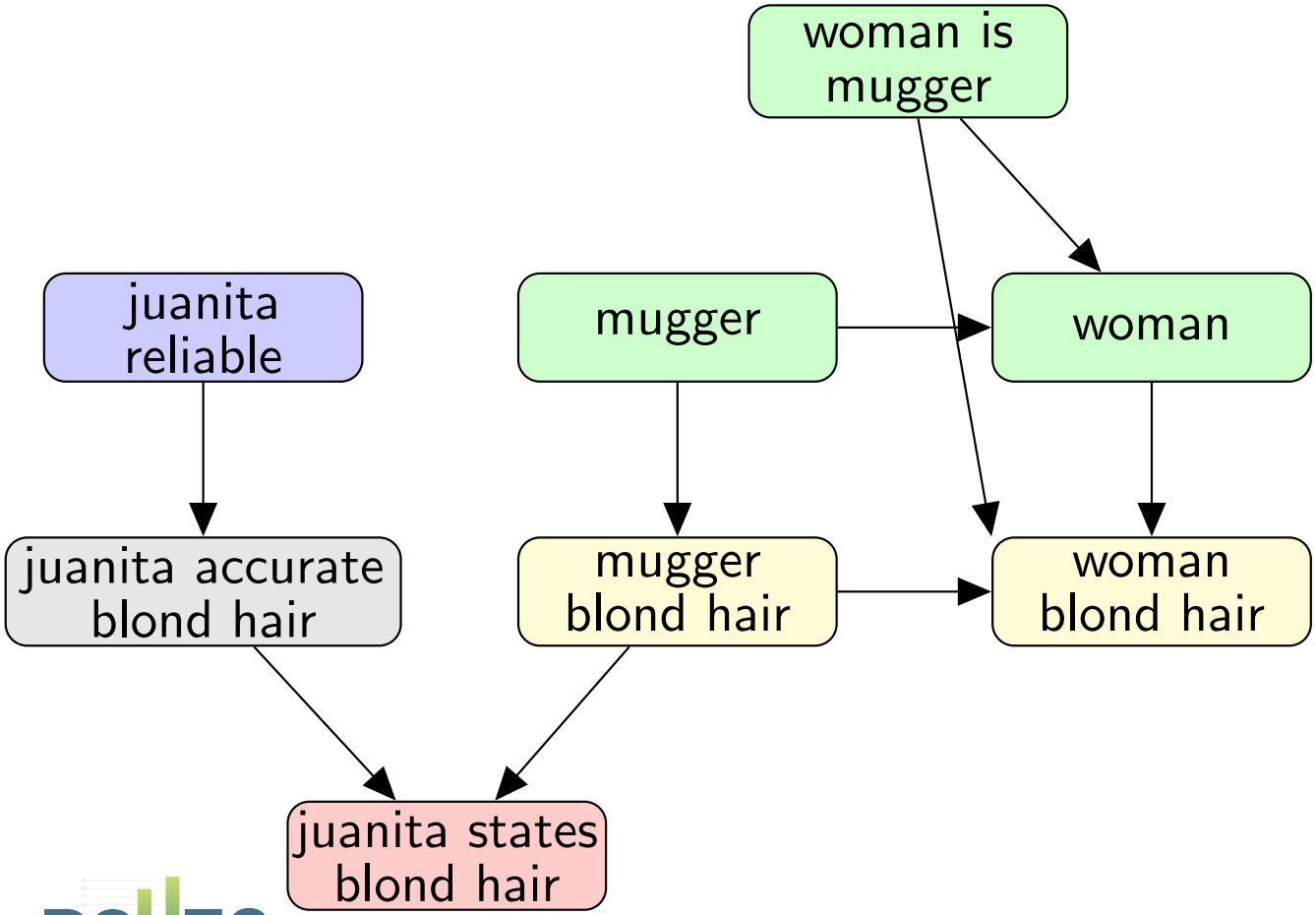
Blond woman evidence



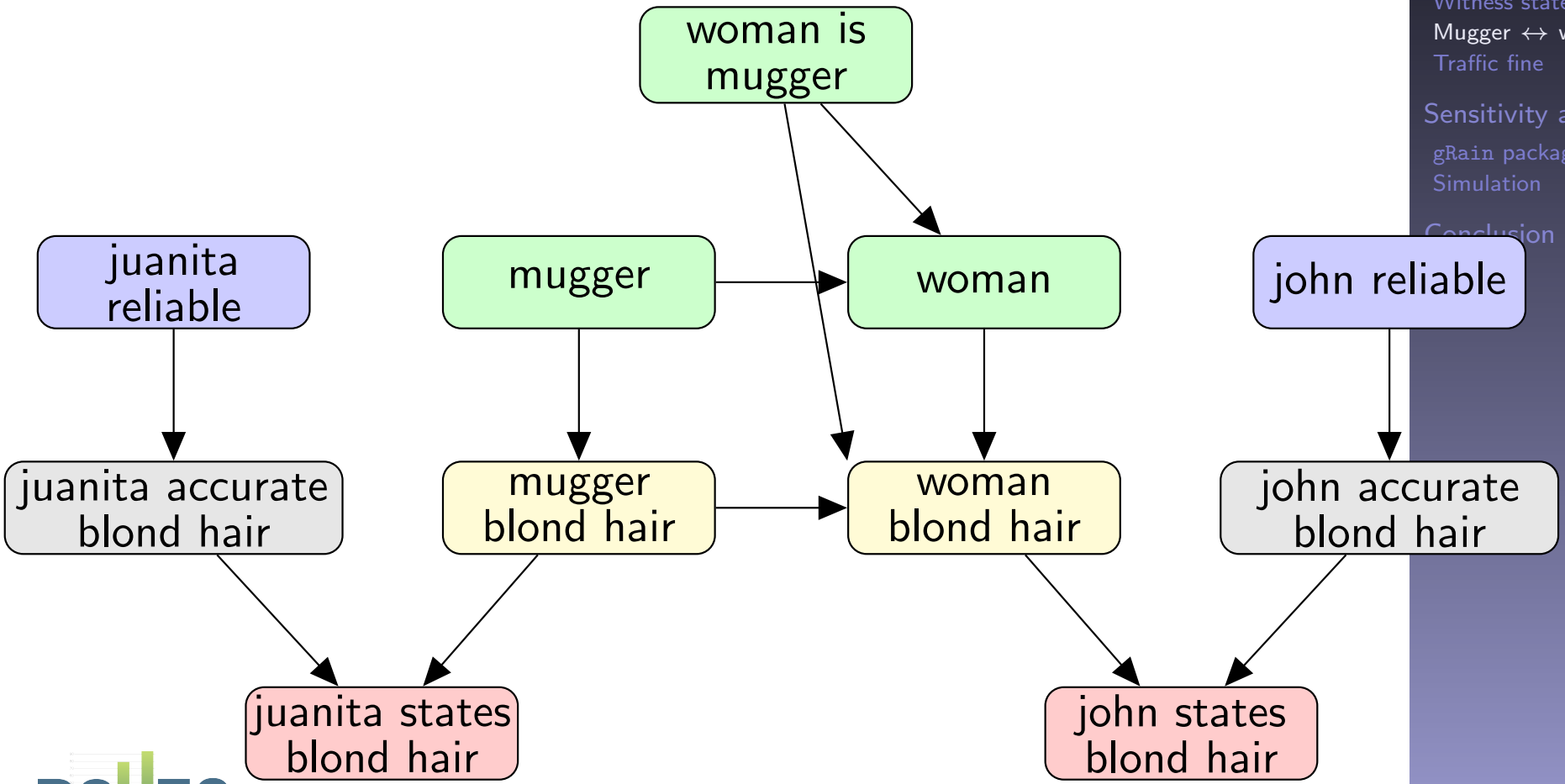
Blond woman evidence



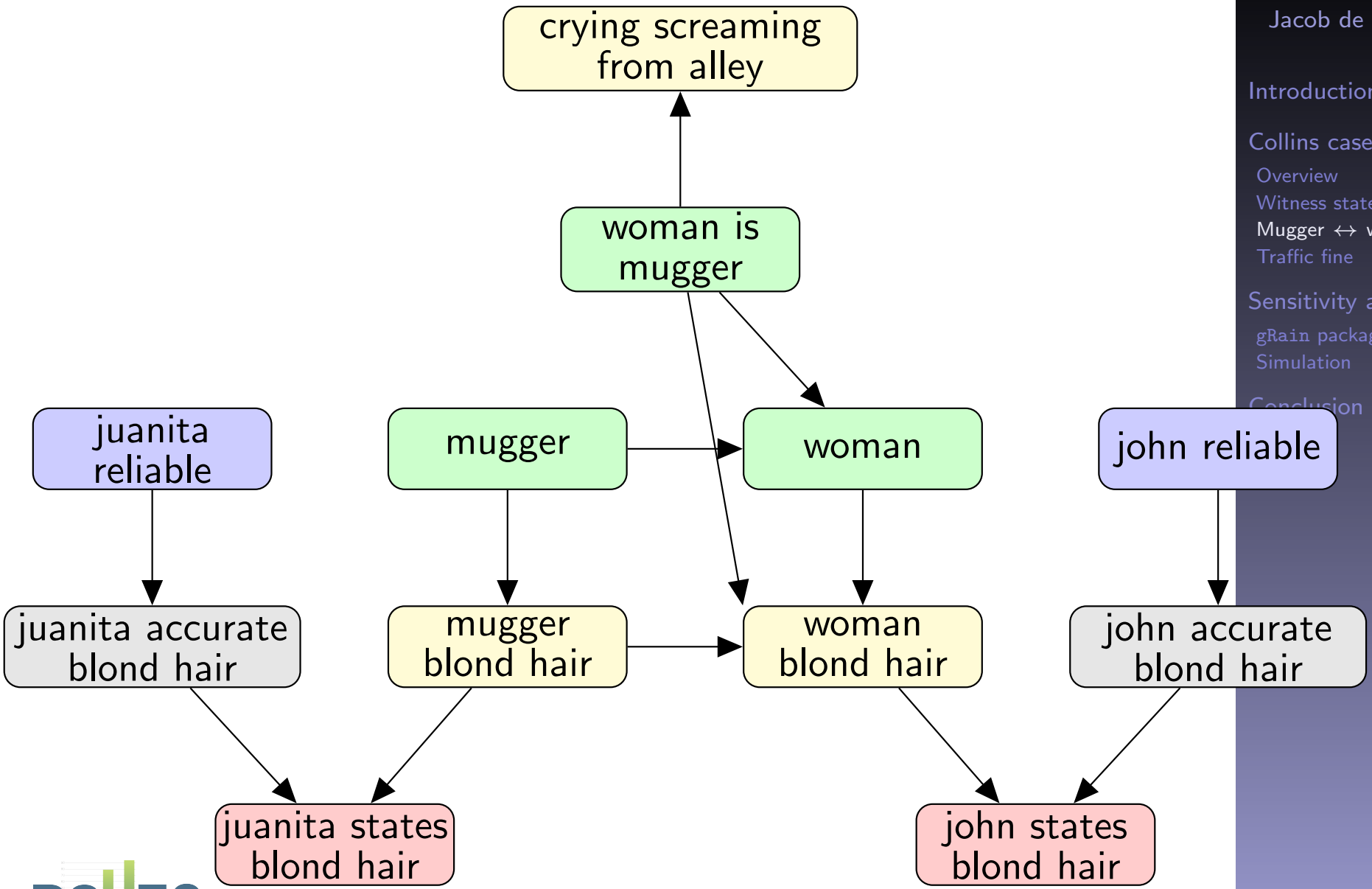
Blond woman evidence



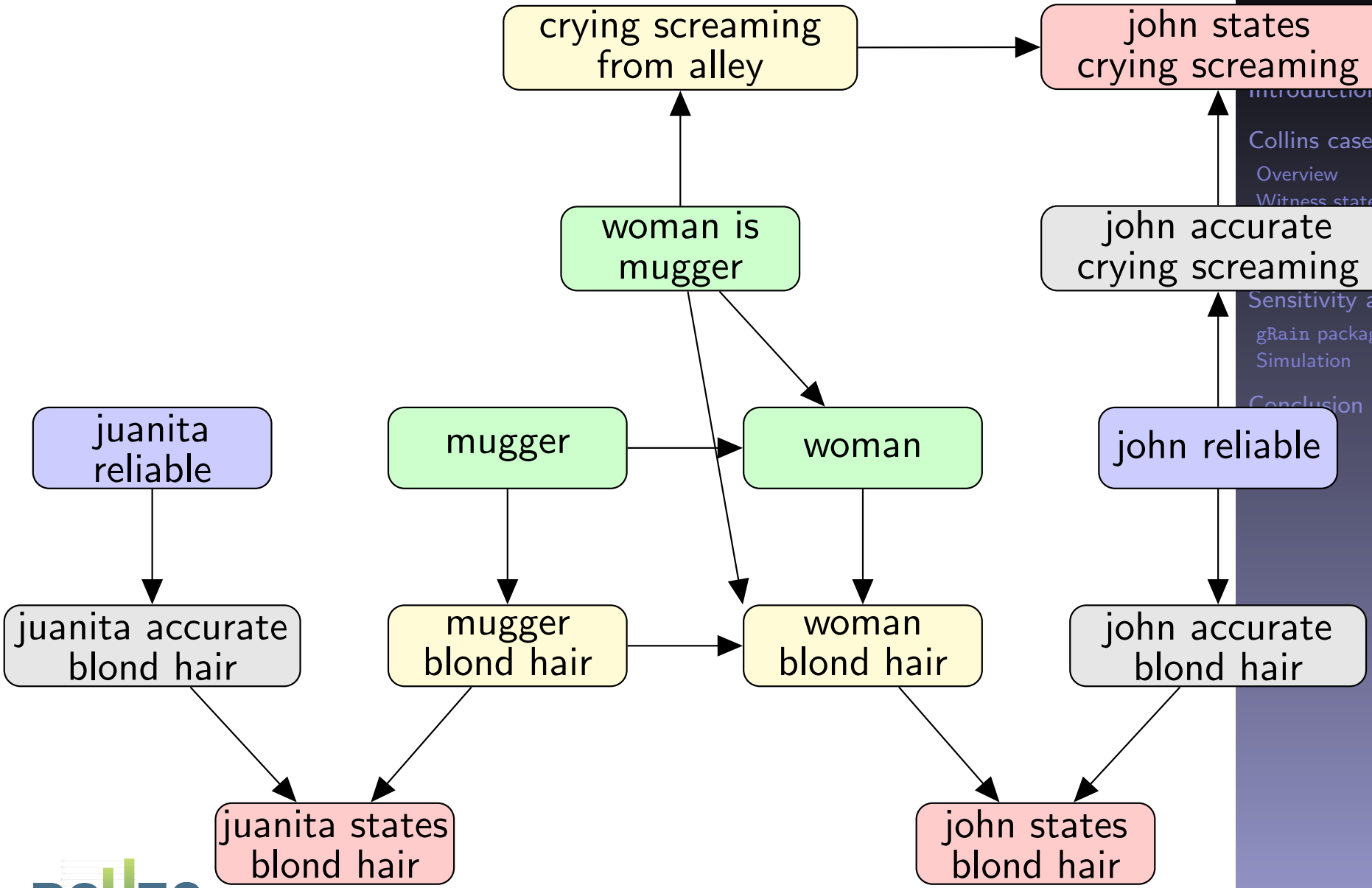
Blond woman evidence



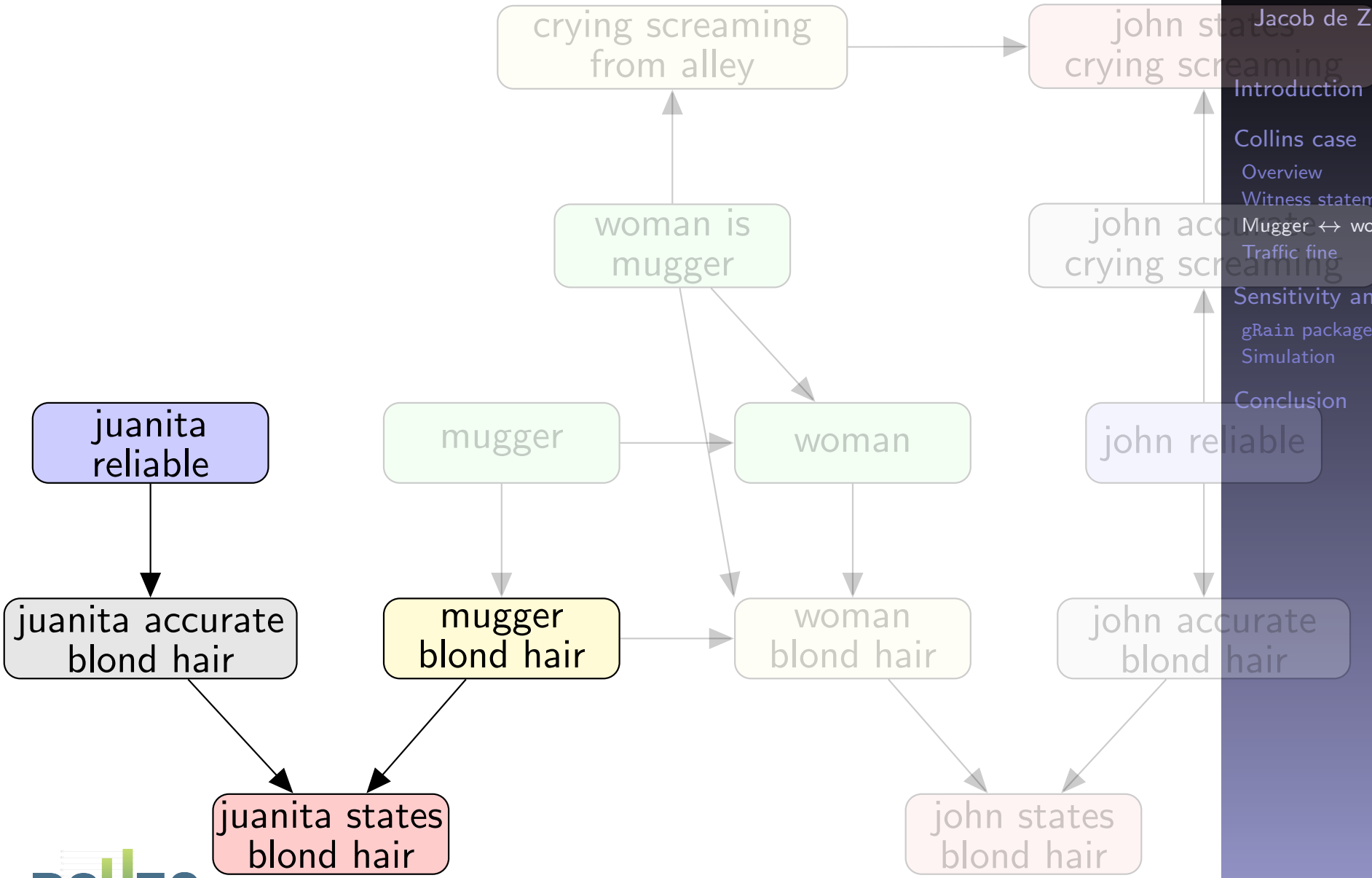
Blond woman evidence



Blond woman evidence



Blond woman evidence



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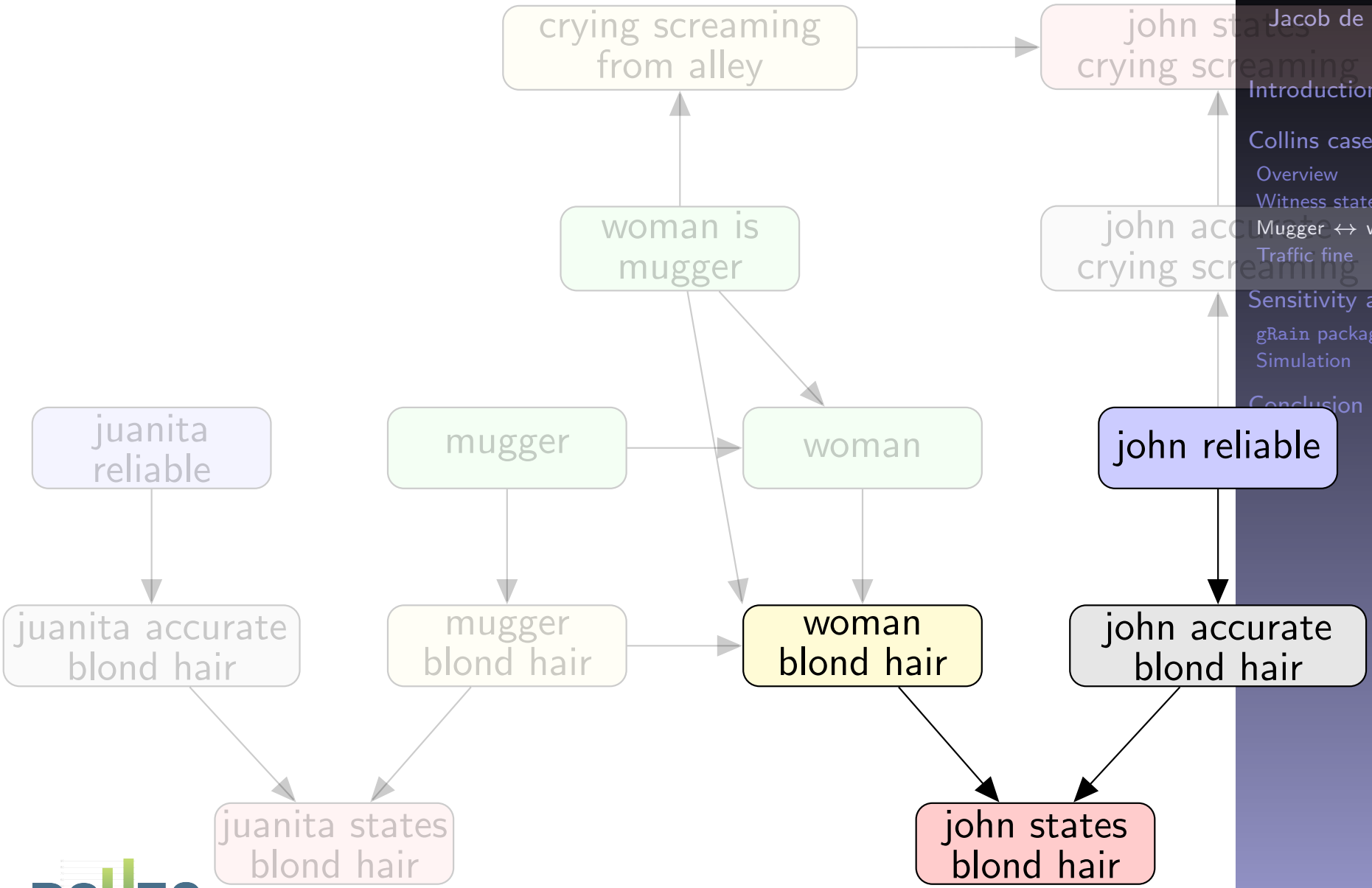
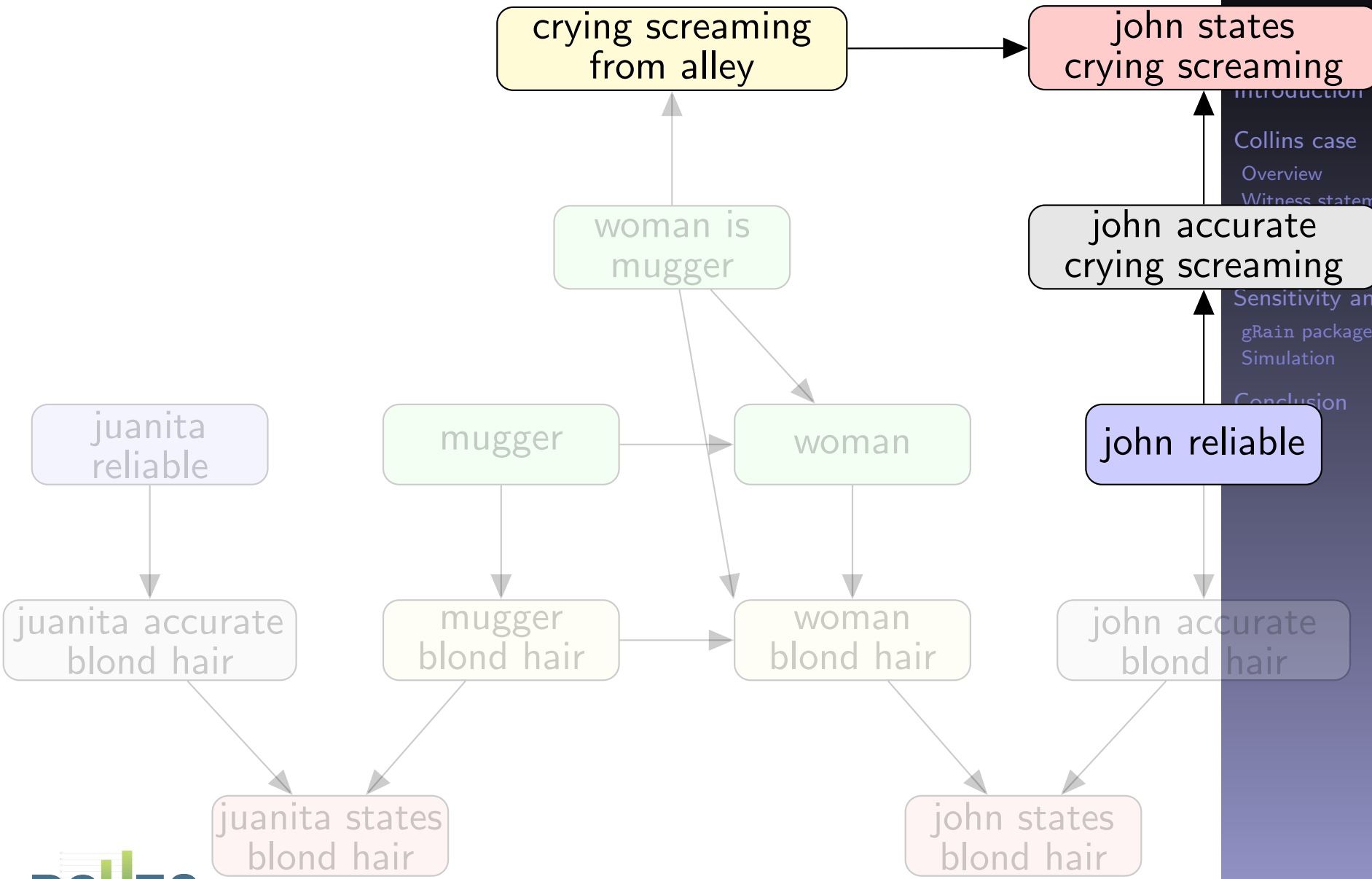


Blond woman evidence



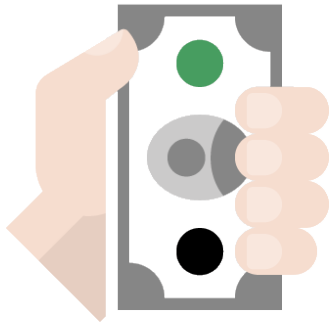
Malcolm - Money on June 18

While in custody, the police searched Malcolm and found receipts for $35 in traffic fines paid on the day after the robbery. This amount matched the amount in the stolen purse. Malcolm said he had won the money gambling, but Janet said the money came from her earnings.

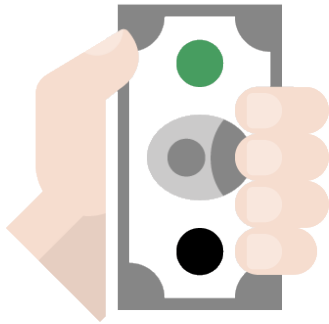
Malcolm - Money on June 18

Malcolm - Money on June 18

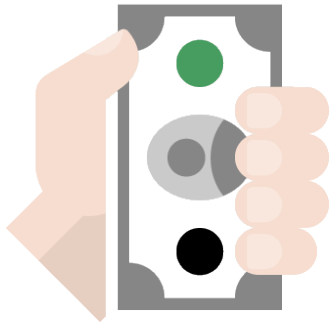
Malcolm - Money on June 18



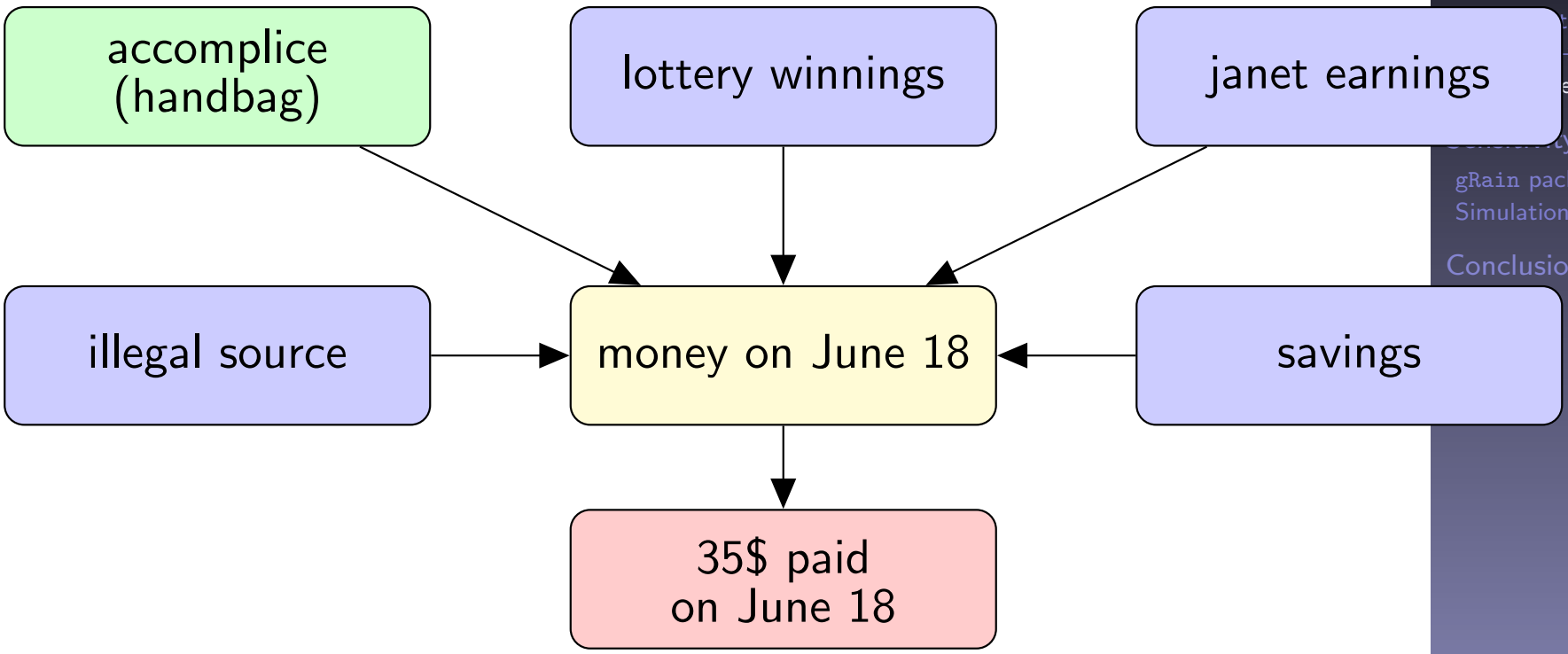
Malcolm - Money on June 18



Malcolm - Money on June 18



net


accomplice
(handbag)
lottery winnings
janet earnings
illegal source
money on June 18
savings
35$ paid
on June 18

Distribution

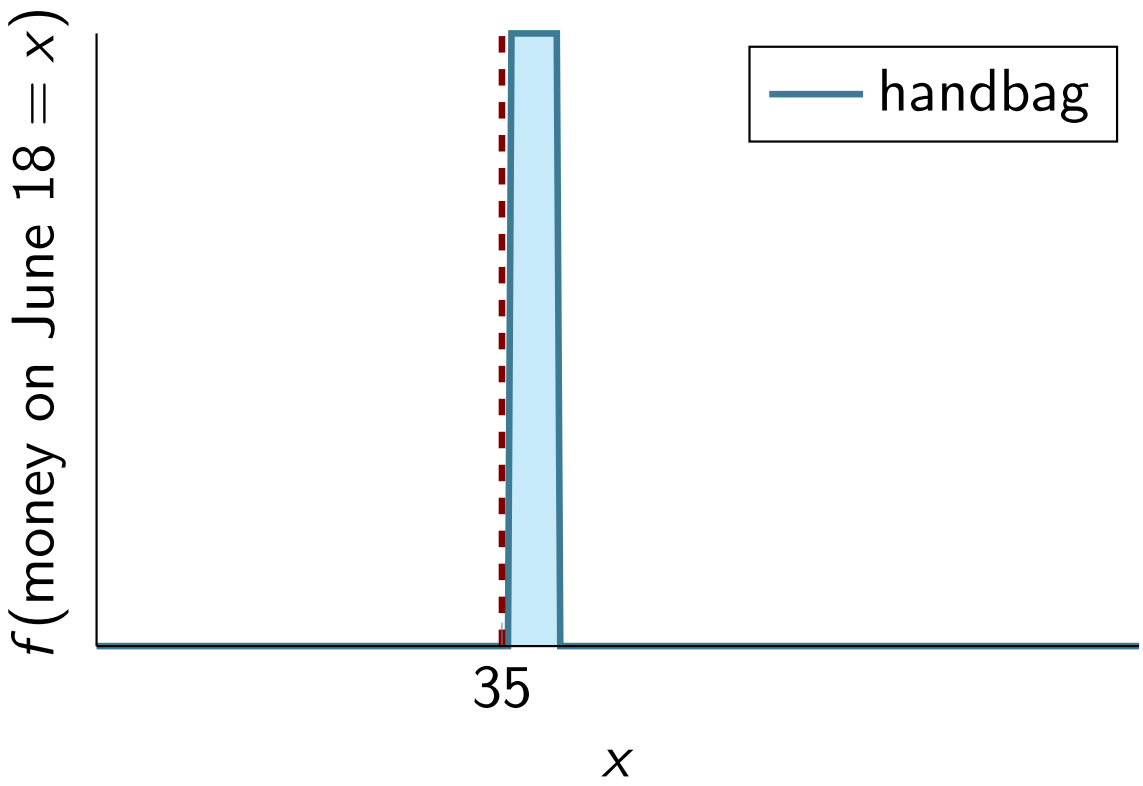


Figure: Conditional distribution `money on June 18`

Distribution

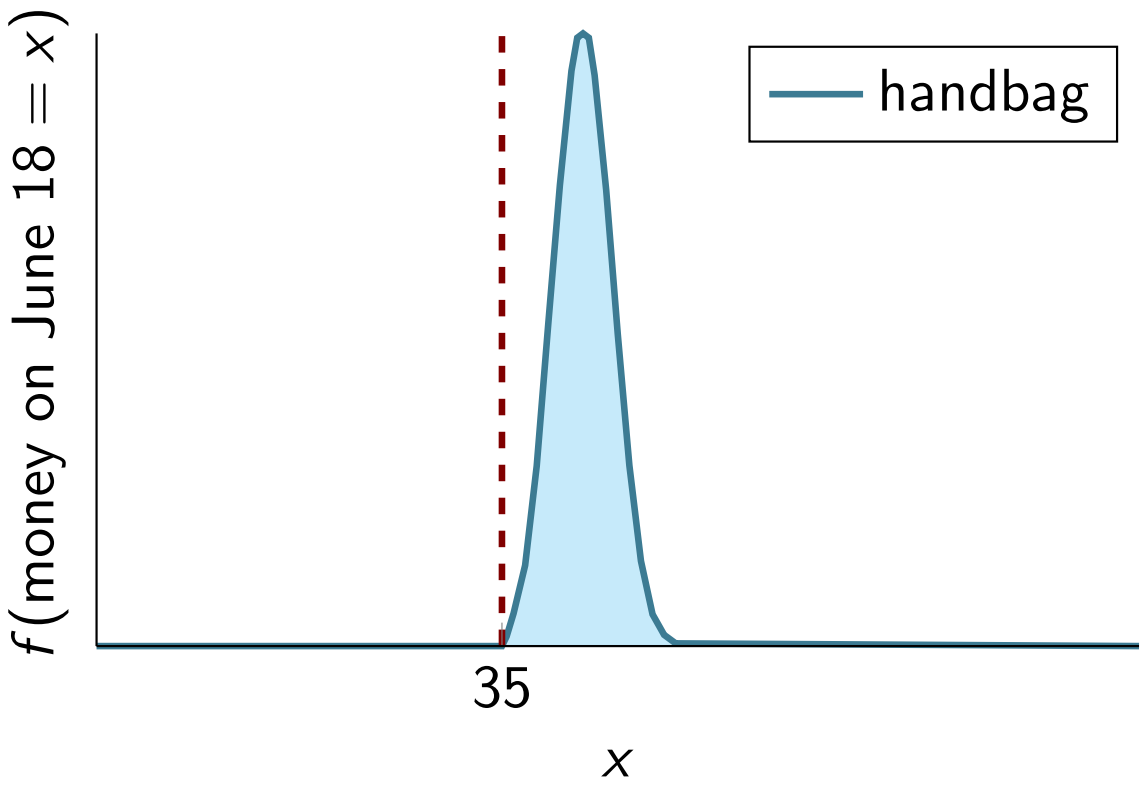


Figure: Conditional distribution `money on June 18`

Distribution

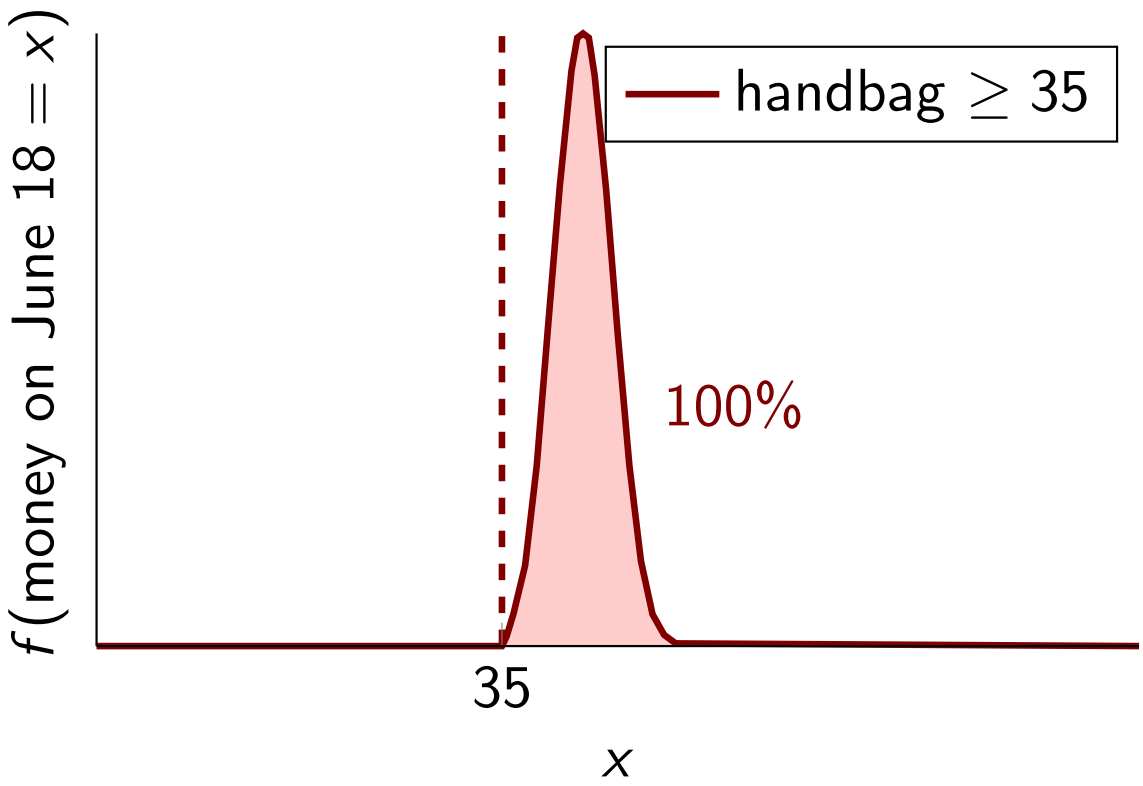


Figure: Conditional distribution `money on June 18`

Distribution

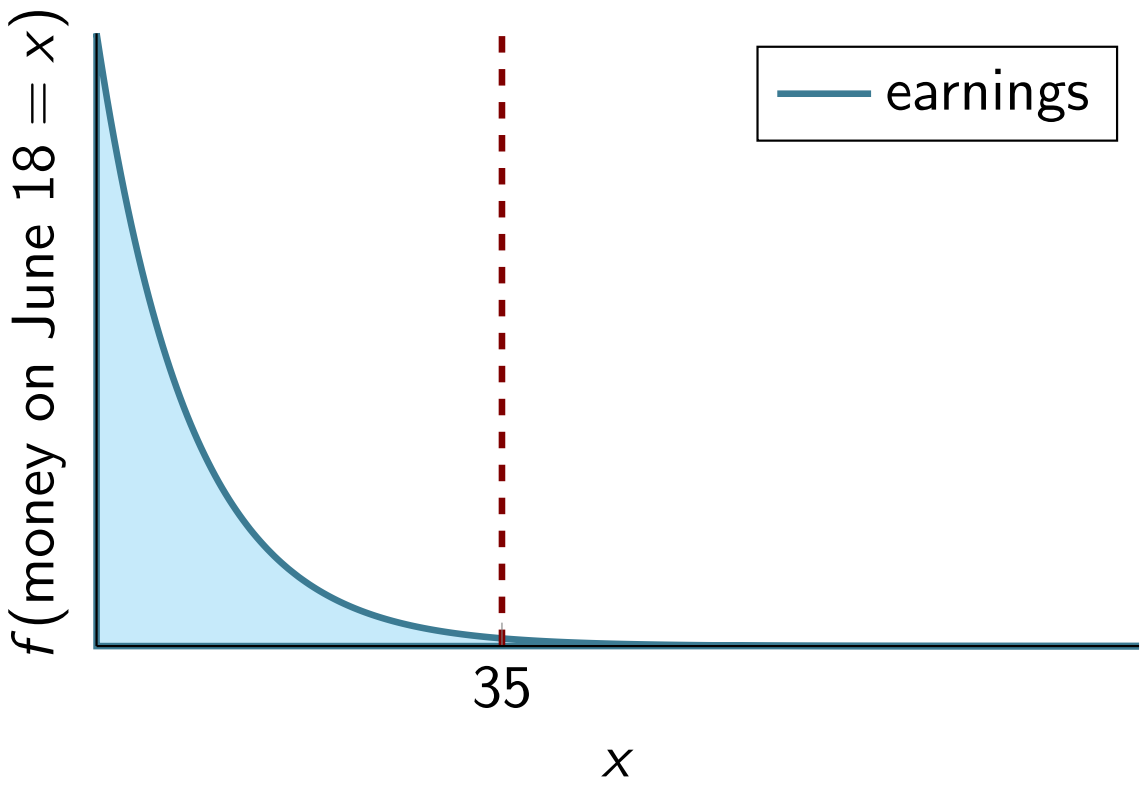


Figure: Conditional distribution `money on June 18`

Distribution

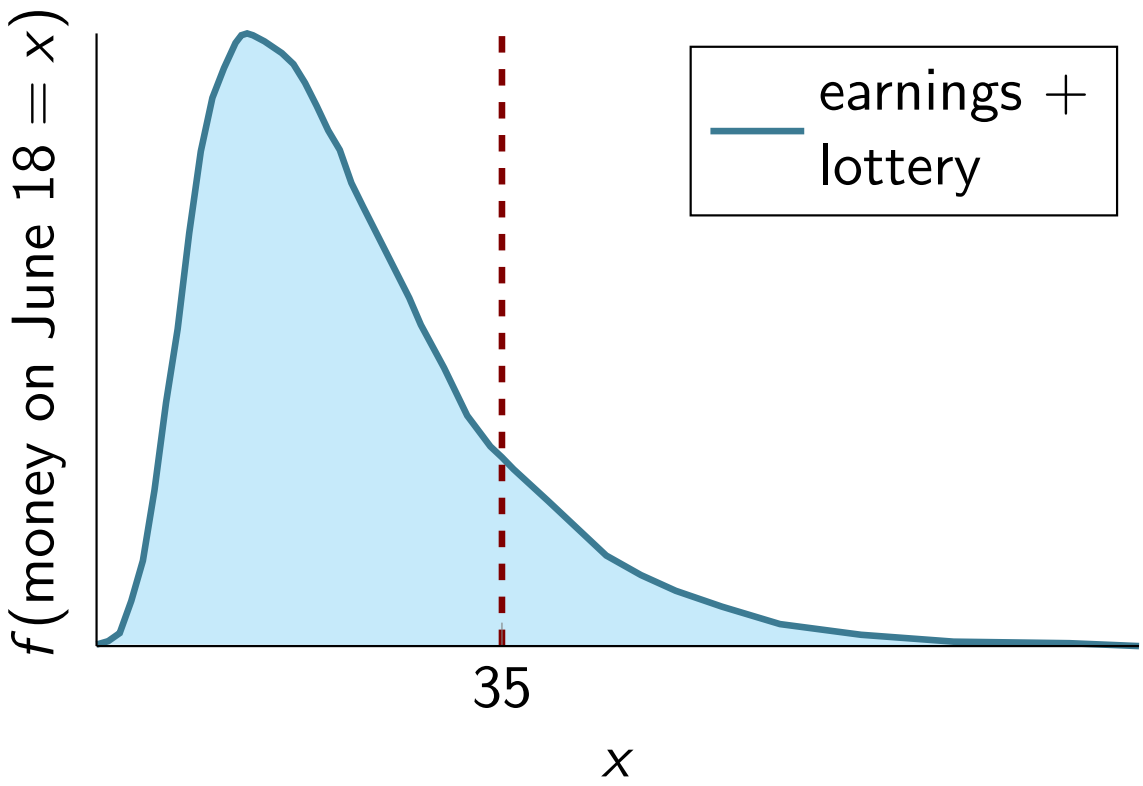


Figure: Conditional distribution `money on June 18`

Distribution

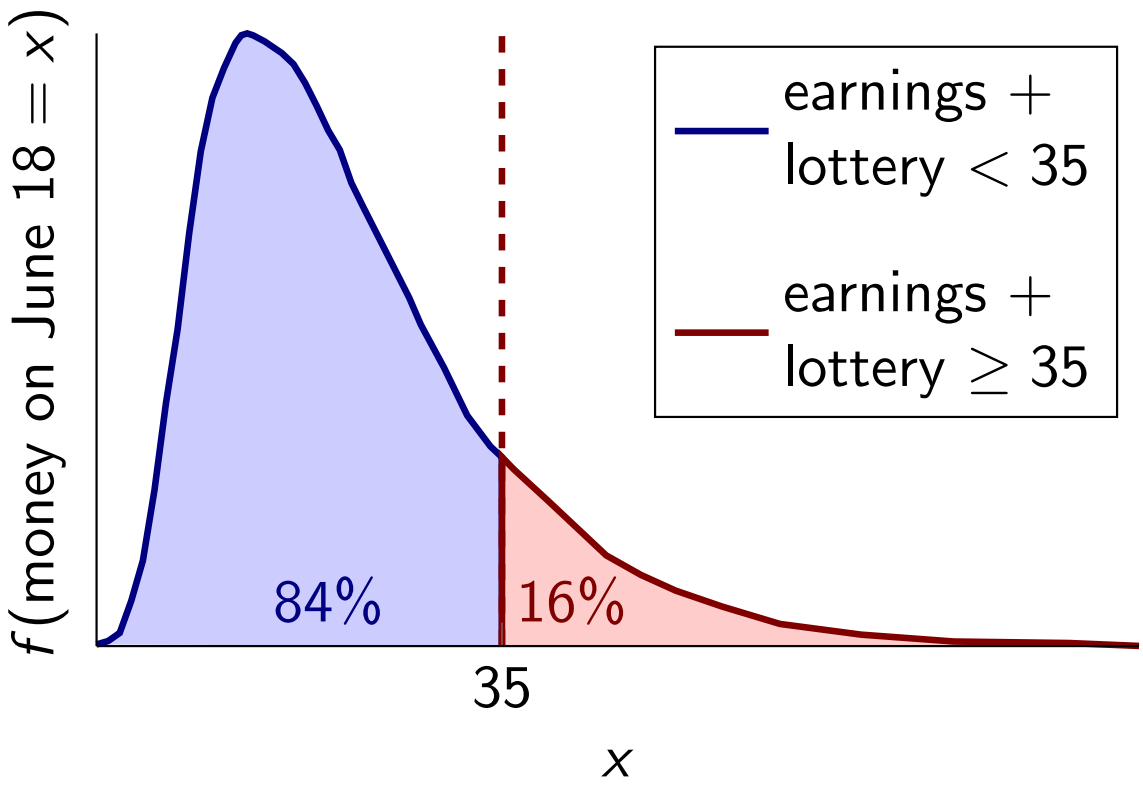


Figure: Conditional distribution `money on June 18`

Money evidence

$$\frac{\Pr(\text{35\$ on June 18} \mid \text{accomplice (handbag)})}{\Pr(\text{35\$ on June 18} \mid \text{[lottery, janet earnings]})} = \frac{100}{16} = 6.25$$

gRain package

```
jb.r <- cptable(~john_bass_reliable,                    1
                levels  = c("true","false"),            2
                values  = c(0.7, 0.3))                  3
```

gRain package

```
jb.r <- cptable(~john_bass_reliable,   → node name                1
                levels  = c("true","false"),                      2
                values  = c(0.7, 0.3))                            3
```

gRain package

```
jb.r <- cptable(~john_bass_reliable,                    1
                levels  = c("true","false"), → states   2
                values  = c(0.7, 0.3))                  3
```

gRain package

```
jb.r <- cptable(~john_bass_reliable,                    1
                levels  = c("true","false"),            2
                values  = c(0.7, 0.3)) → probability table  3
```

gRain package

```
jb.r <- cptable(~john_bass_reliable,                                    1
                levels  = c("true","false"),                            2
                values  = c(0.7, 0.3))                                  3

jb.a <- cptable(~john_bass_accurate_blond_hair + john_bass_reliable,    4
                levels  = c("true","false"),                            5
                values  = c(0.9, 0.1, 0.0, 1.0))                        6
```

gRain package

```
jb.r <- cptable(~john_bass_reliable,                                  1
                levels  = c("true","false"),                          2
                values  = c(0.7, 0.3))                                3

jb.a <- cptable(~john_bass_accurate_blond_hair + john_bass_reliable,   4
                levels  = c("true","false"),                          5
                values  = c(0.9, 0.1, 0.0, 1.0))                      6
```

→ *node parents*

Sensitivity analysis - reliable

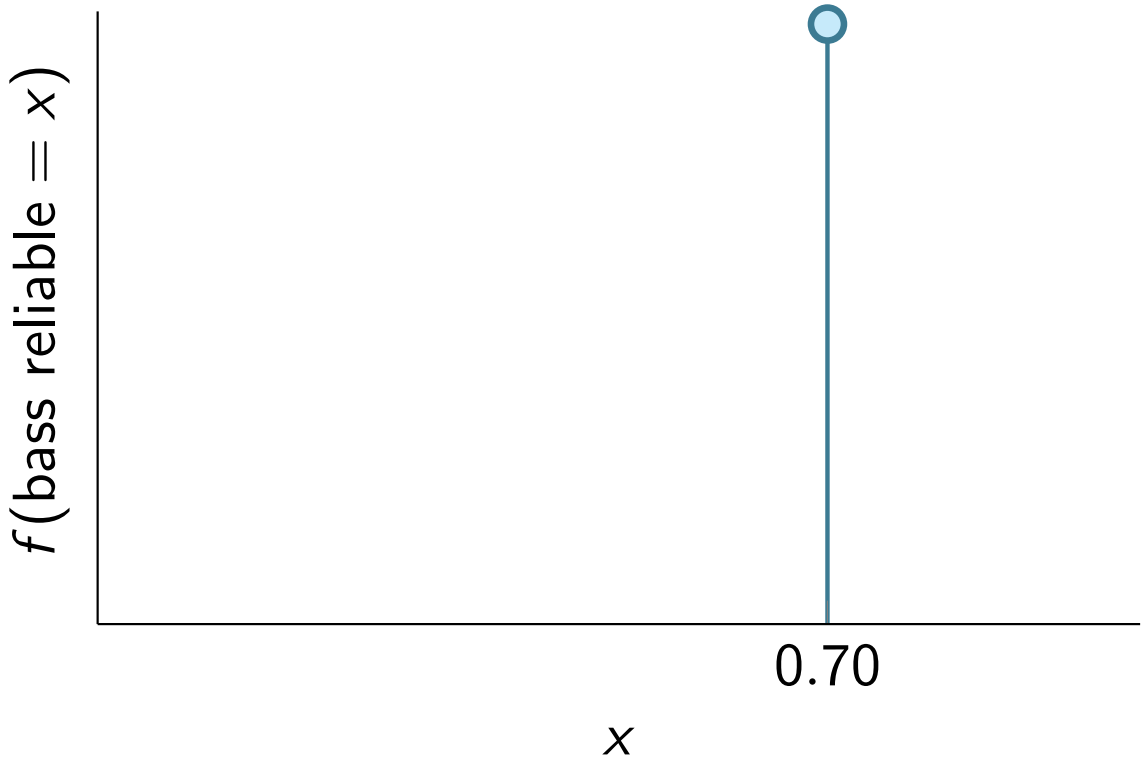


Figure: Prior probability `John Bass reliable`

Sensitivity analysis - reliable

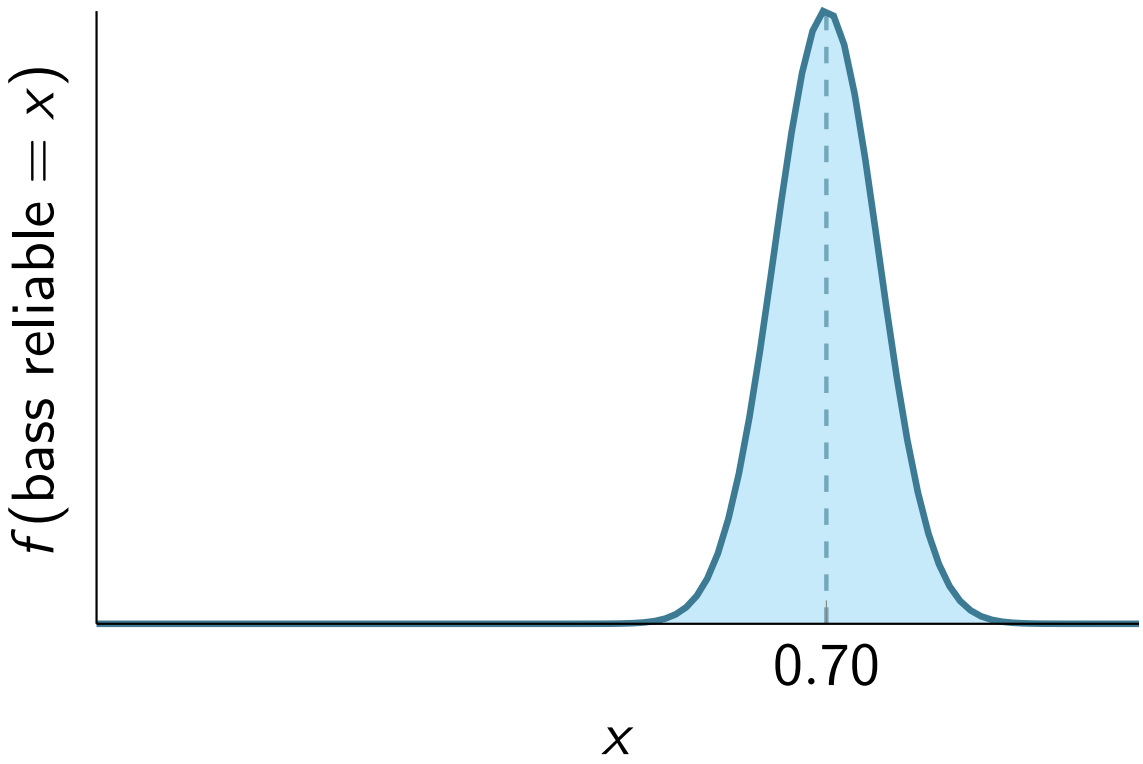


Figure: Prior probability `John Bass reliable`

Sensitivity analysis - accurate

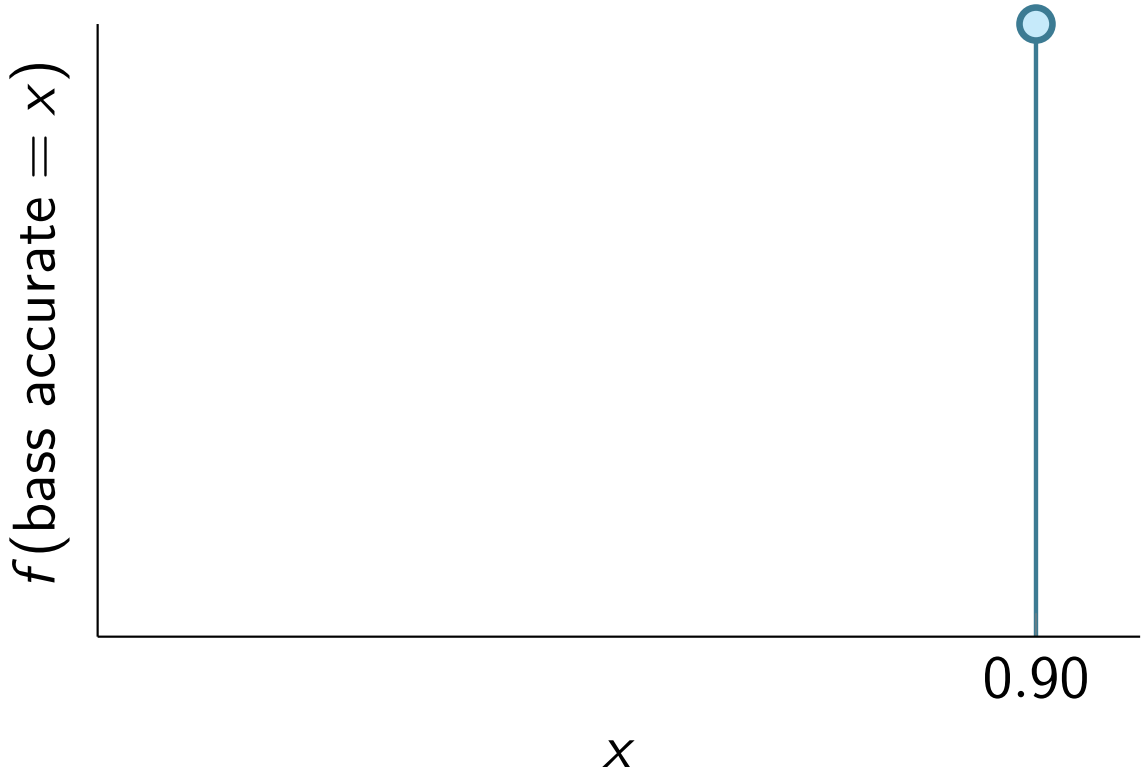


Figure: Cond. probability `John Bass accurate blond hair`

Sensitivity analysis - accurate

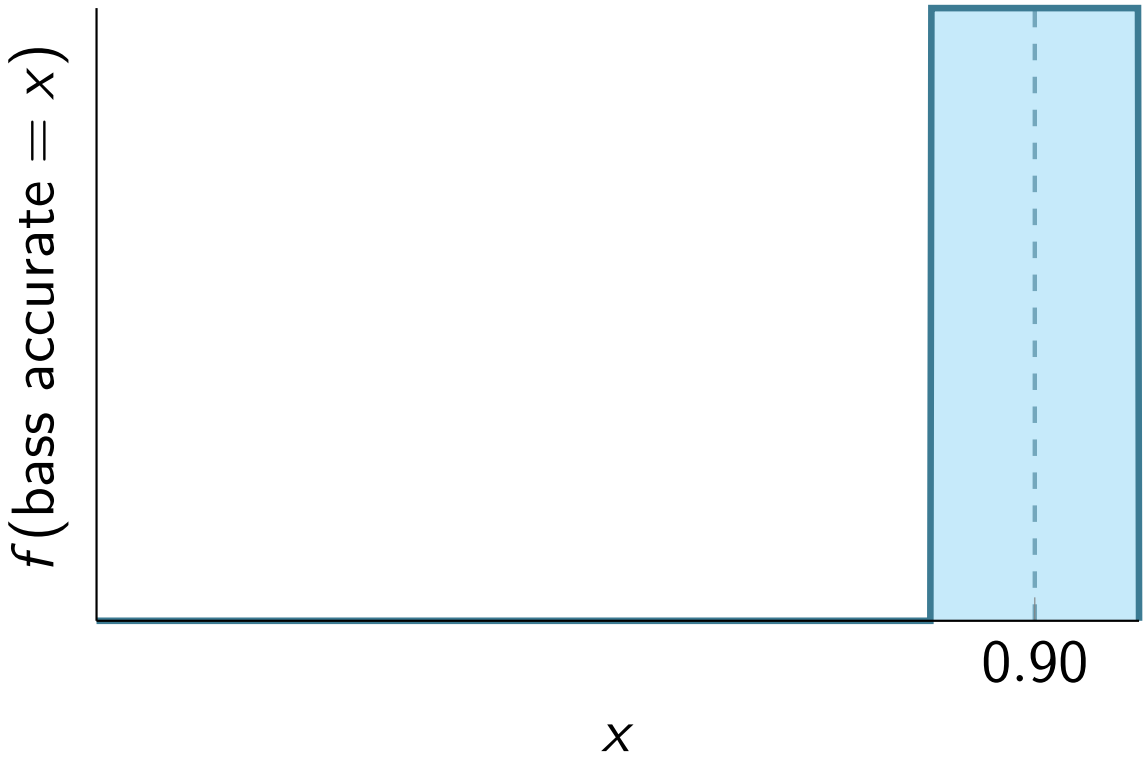


Figure: Cond. probability `John Bass accurate blond hair`

Simulation

```
jb.r <- cptable(~john_bass_reliable,
                levels  = c("true","false"),
                values  = c(0.7, 0.3))

jb.a <- cptable(~john_bass_accurate_blond_hair + john_bass_reliable,
                levels  = c("true","false"),
                values  = c(0.9, 0.1, 0.0, 1.0))
```

Simulation

```
N           <- 1000
p.reliable  <- rnorm(N, 0.70, 0.05) # normal distribution
p.accurate  <- runif(N, 0.80, 1.00) # uniform distribution
```

```
jb.r <- cptable(~john_bass_reliable,
                levels  = c("true","false"),
                values  = c(0.7, 0.3))

jb.a <- cptable(~john_bass_accurate_blond_hair + john_bass_reliable,
                levels  = c("true","false"),
                values  = c(0.9, 0.1, 0.0, 1.0))
```

Simulation

```
N           <- 1000
p.reliable  <- rnorm(N, 0.70, 0.05) # normal distribution
p.accurate  <- runif(N, 0.80, 1.00) # uniform distribution
```

```
for(i in 1:N){
  jb.r <- cptable(~john_bass_reliable,
                  levels  = c("true","false"),
                  values  = c(p.reliable[i], 1-p.reliable[i]))

  jb.a <- cptable(~john_bass_accurate_blond_hair + john_bass_reliable,
                  levels  = c("true","false"),
                  values  = c(p.accurate[i], 1-p.accurate[i], 0.0, 1.0))
}
```

Sensitivity analysis

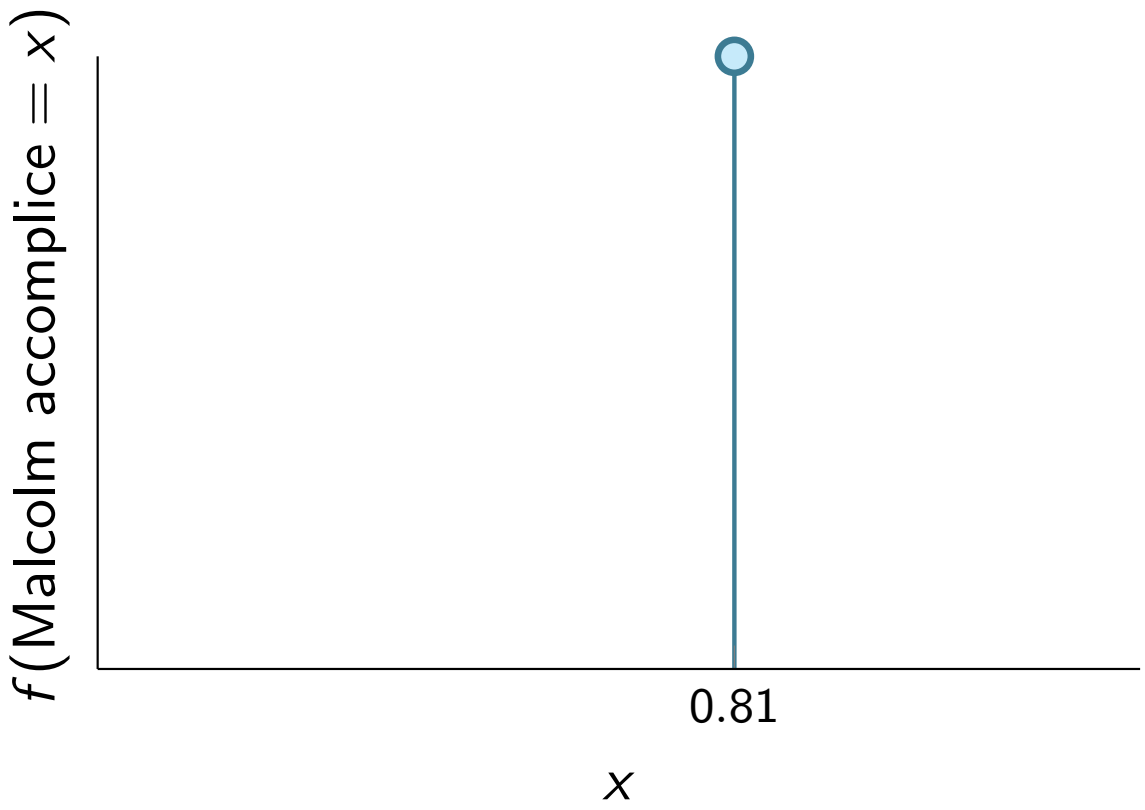


Figure: Post. probability `Malcolm accomplice`

Sensitivity analysis

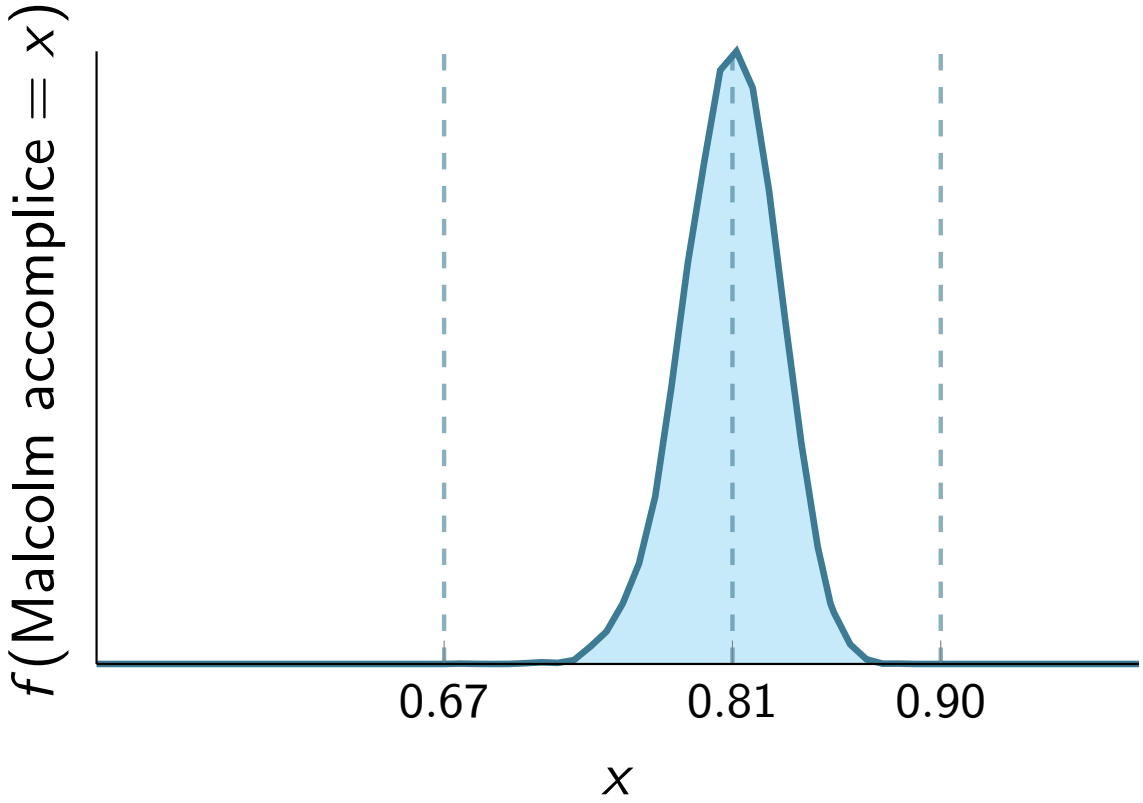


Figure: Post. probability `Malcolm accomplice`

Sensitivity analysis

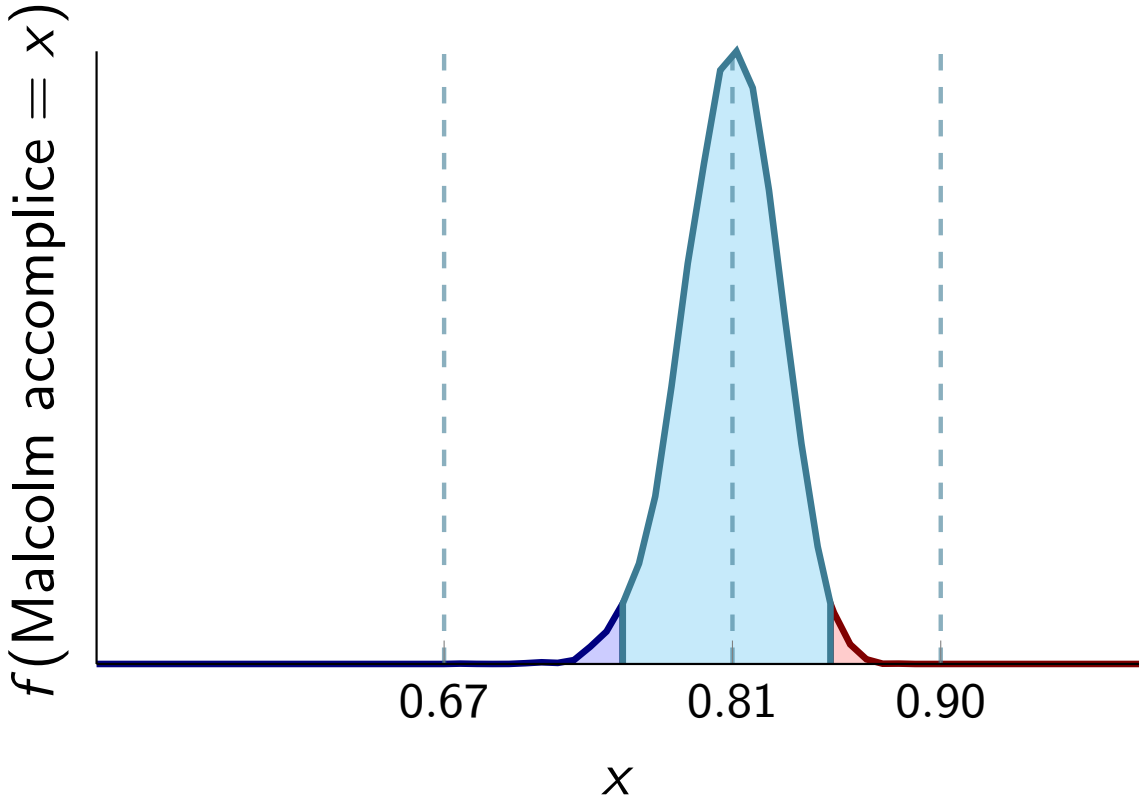
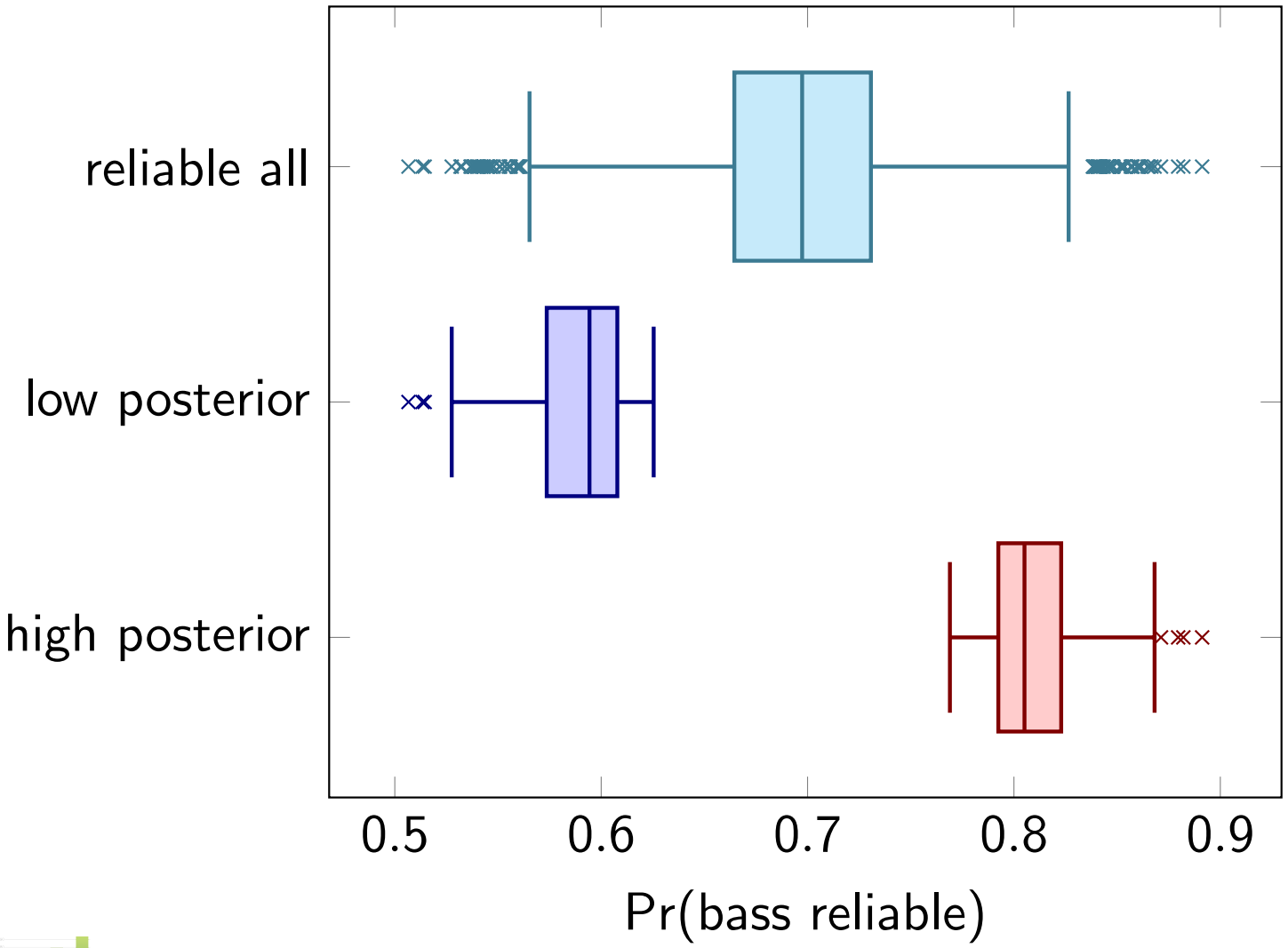
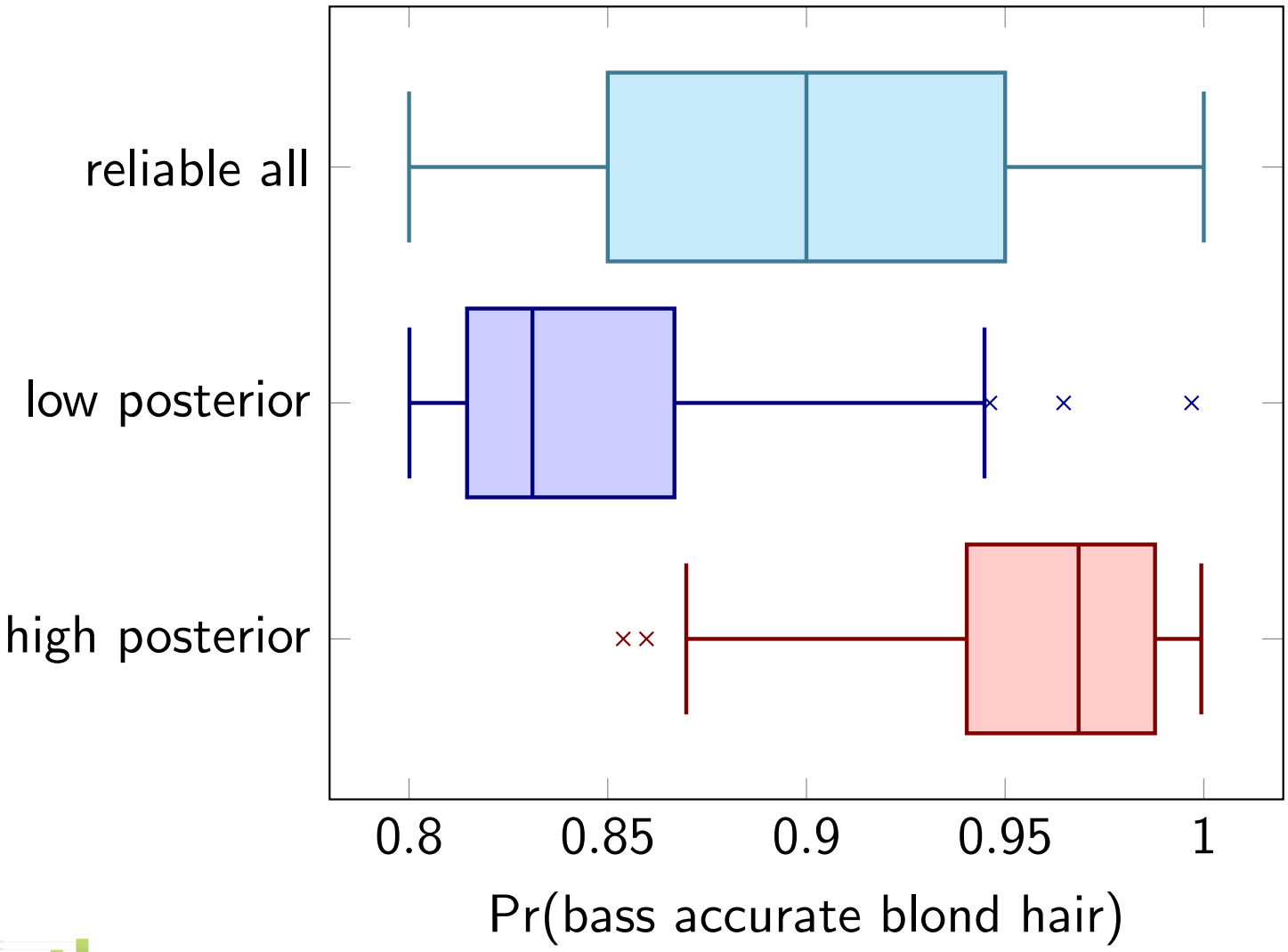


Figure: Post. probability `Malcolm accomplice`

Outliers


reliable all
low posterior
high posterior
0.5
0.6
0.7
0.8
0.9
Pr(bass reliable)

Outliers


reliable all
low posterior
high posterior
0.8
0.85
0.9
0.95
1
Pr(bass accurate blond hair)

Conclusion

- Idioms for pieces of evidence simplify the construction of complex case models.
- The proposed method of sensitivity analysis can help - especially for complex cases - to determine whether there is sufficient evidence for a case to be brought to court
- (R) programming allows for a more 'thorough' sensitivity analysis, for example by allowing for ranges or distributions for probability estimates instead of point estimates.

Acknowledgments

This work is supported by the ERC project BAYES_KNOWLEDGE (**ERC-2013-AdG339182**)

European Research Council

Established by the European Commission